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AN INVESTIGATION OF POTENTIAL USES OF ANIMALS IN COAST GUARD OPERATIONS

BY

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16. Abstract

The primary objective of the study was the identification of the capabilities and behavioral characteristics of animals which were potentially useful in assisting the Coast Guard in the fulfillment of its mission requirements and mission performance. Capabilities are identified as olfaction (smell), vision, sound, echolocation, electromagnetism, chemoreception. For example, the use of dogs' olfactory capabilities to detect explosives. A review of forecasts made for the Coast Guard were used as a background for the conduct of the study. Recommendations are made for a Coast Guard Program to pursue research and development of promising animal system concepts.

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EXECUTIVE SUMMARY

OBJECTIVES

The primary objective of this project is to identify potential uses of the capabilities of animals which could assist the Coast Guard in the fulfillment of its mission requirements and mission performance. The focus is on the next five to twenty-five years. Also, likely uses, legal and illegal, of animals by others with whom the Coast Guard interacts are explored. Finally, recommendations are made for a Coast Guard program to pursue research and development of promising animal system concepts.

APPROACH

A summary of the study plan is shown in Figure 1. Coast Guard forecasts were reviewed and missions analyzed. Animal capabilities were investigated by a review of the research literature and by collecting information on past and current uses of animals. Then, system concepts for use of animals by the Coast Guard were formulated and evaluated. Likely uses, legal and illegal, of animals by others were assessed. Finally, recommendations were made for a program of animal system development projects and further investigations.

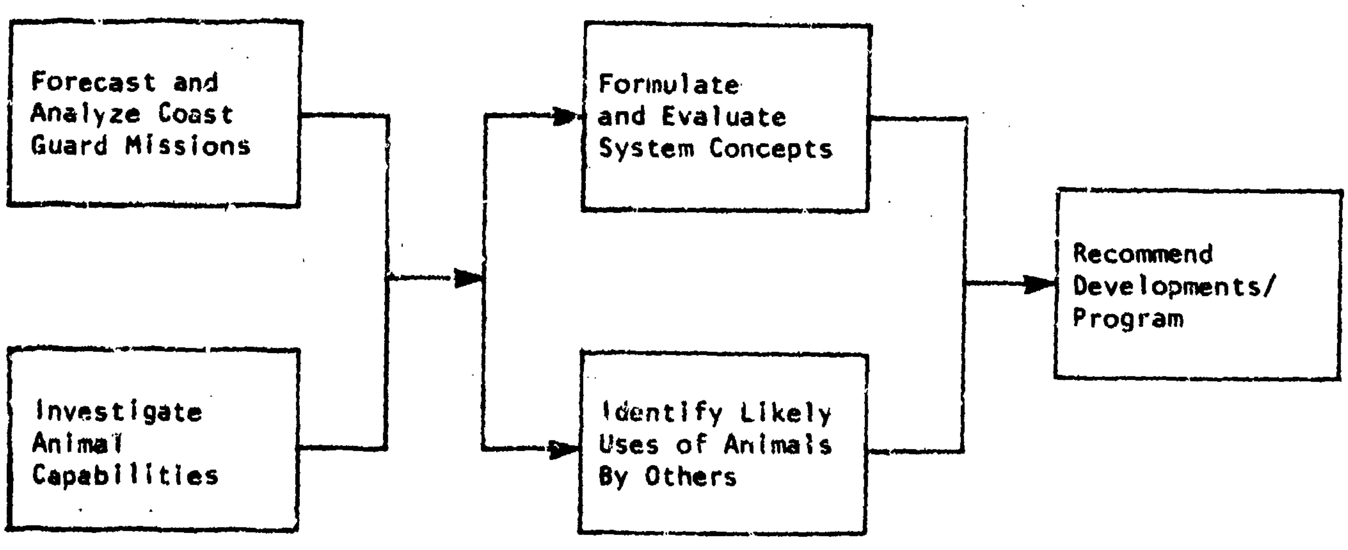

Figure 1. Summary of Study Plan

COAST GUARD FORECASTS

The review of forecasts made for the Coast Guard revealed predictions of steady development and utilization of marine resources. The likelihood of extending the 200 mile fishing control area to all economic activities was indicated. Oil and gas exploration and production will continue to dominate offshore industrial operations.

Sea trade and world shipping capacity will increase. Traffic congestion in ports and port approaches will be worse. The diversity of ships in terms of size and type will broaden. More hazardous cargoes will be carried.

More of the population will live near the coast. Likewise, more industry will locate there. The combination of these factors will lead to greater exposure to and consequences of natural and man-made disasters. Greater use will be made of the marine environment for recreation, including underwater activities.

Terrorist activities may be directed against the U.S., and assets in the marine environment could become targets. Smuggling of narcotics and illegal aliens is expected to grow.

Development of the marine environment will cause it to become a reason for conflict. Nations will declare claims on assets unilaterally or reach bi- or multilateral agreements. More potential is seen for armed conflicts because of political instabilities resulting from food, energy, and other resource scarcities.

COAST GUARD MISSIONS

The impact of the different forecasts on each Coast Guard mission was subjectively quantified in a matrix. Then, selected missions were analyzed and the following conclusions were drawn.

Terrorism Control

In general, it was concluded that sensor and onboard security forces are needed to control the terrorist threats to some high value offshore assets. Area surveillance and patrols and a quick response force also would be worthwhile.

It would be relatively easy for terrorists to take over a large ship with hazardous cargo and threaten a population center. Cruise ships also are potential terrorist targets.

Control of Smuggling

Selecting likely smugglers from among the many ships/boats sighted is a significant problem.

Search and Rescue

Analysis of SAR statistics indicated the possible value of improving the search capability of Coast Guard boats. Lack of an effective nighttime search capability also was revealed. Underwater recovery of submersibles may be a future role.

Pollution Control

The Coast Guard's main concerns have been the control of oil spills and the detection of intentional pumping of oily wastes from ships. In the future, the Coast Guard may have more responsibility for inspection of oil exploration and production equipment with respect to pollution control. The detection, plotting the extent of, and controlling the effects of accidents with other hazardous materials also will gain in importance.

Military Operations

Combat search and rescue is a natural and important mission for the Coast Guard. SAR resources will also be useful in cases of natural

disasters. Defense against swimmer attacks and protection of offshore assets by small units would seem to be natural extensions of anticipated peacetime missions. It would also be valuable if the Coast Guard had the capability to detect and neutralize mining of ports and port approaches.

PAST AND CURRENT USES OF ANIMALS

Mobility and sensory capabilities of animals have been exploited often. The earliest use of pigeons for communication dates to 4500 B.C. That use has continued to modern times, including frequent battlefield use of pigeons in World War I. Animals have been employed in sentry roles and for tracking people. The Israeliis and British have body searching teams which employ dogs. The U.S. Army developed a system in which dogs searched for and located land mines. The U.S. Navy has developed systems which employ sea lions and small whales. Fundamental to all trained animal systems are the learning models of operant and classical conditioning.

Currently, there are several federal agencies employing dogs for narcotics and explosives detection. Users include the Federal Aviation Administration, U.S. Customs Service, the Armed forces, and the Secret Service. Experimentation is underway on the use of rats or gerbils for explosives detection.

The Coast Guard is sponsoring development of a system, called Sea Hunt, which uses pigeons in a module under a helicopter or aircraft to locate people in life vests or rafts in the water.

ANIMAL CAPABILITIES

To generalize from the survey of animal capabilities, the sensory qualities most useful in systems and the types of animals possessing these qualities are:

Animal	Sense
• Bacteria	Chemoreception
• Insects	Olfaction
• Fish (including sharks and rays)	Olfaction, vibration, electromagnetism
• Rodents	Olfaction
• Birds	Vision (day and night), possibly olfaction
• Dogs	Olfaction
• Pigs	Olfaction
• Marine mammals	Audition and echolocation

The potential use of the sense of smell is noteworthy. It is a sense which is highly develope and used by many animals but not so much by man. Therefore, the animals contribute something unique. Likewise, echolocation by porpoises provides a special search capability. While man makes good use of vision, some birds are superior. Owls have far better night vision, hawks and eagles have greater acuity, and pigeons have the same acuity as man but over a wider field of view. Birds are also more attentive than man to search tasks over prolonged periods.

In addition to the special sensory capabilities of the animals, other qualities can be utilized. The small size of bacteria, insects, rodents, and birds makes them easily transportable. They can also be bred rapidly. The diving and mobility of marine mammals and fish can be exploited as well as the flight of birds.

SUGGESTED USES OF ANIMALS BY THE COAST GUARD

Technical feasibility and effectiveness of the Sea Hunt SAR system has been demonstrated. Introduction of Sea Hunt to Coast Guard operational units is recommended.

Approximately fifty ideas were generated for use of animals in Coast Guard missions. These were evaluated according to criteria selected earlier in the study. The following applications/projects are suggested for immediate consideration by the Coast Guard.

- A bird launched from Coast Guard boats to find people in life vests, rafts, or disabled boats. This will extend the visual field of the searchers.
- A night version of the Sea Hunt airborne search system. The system would use an owl in the module instead of pigeons. Owls have low intensity vision one hundred times better than man.
- A system to select ships which may be smuggling marijuana. The animal detects the odor of the plant in the air samples. Among the promising candidates for this system is the Northern Fulmar, a bird which appears to have excellent olfactory capabilities.
- Onboard inspection of ships suspected of smuggling drugs. Dogs could be employed and there also is potential value in the use of rats or gerbils.
- A security system to protect offshore and waterfront facilities and ships from intruders. It is suggested that a bird with good night vision, such as an owl, be employed.
- Use of dogs (or another olfactory sensitive animal) to inspect cruise ship passengers for explosives (with the passengers in booths separated from the animals). Luggage also could be inspected.
- A water pollution detection system utilizing bioluminescent bacteria.
- An animal svmbol to enhance Coast Guard public relations and promote specific programs (e.g., boating safety). Trained animals would be used for public and media appearances.
- Potential use of Navy animal systems by the Coast Guard, including underwater object recovery systems.

Recommendations are made on how to proceed with development of these systems.

POTENTIAL USES OF ANIMALS BY OTHERS

Other government agencies will continue to use dogs. The olfactory capability of rodents may be employed in explosives detection systems if current research yields positive results. The Coast Guard Sea Hunt system

could stimulate interest in use of birds. Navy research and development work with marine mammals is expected to continue. A bionic sonar system will be implemented. Work by other agencies will provide a technology base for the Coast Guard to develop its own systems.

Industry is not expected to come up with more innovative uses of animals. Animal use will be mainly in the biomedical, entertainment, and security fields.

Until law enforcement measures become much more effective against the current operating methods of terrorists and criminals, they will not make use of animals to achieve their goals.

CONCLUSION

There are potentially valuable uses of animals by the Coast Guard. Some systems should be considered for development now. The worthiness of future applications may be demonstrated by further investigations.

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Several people at the Naval Ocean Systems Center participated in critiquing all or selected portions of the report. They include Dr. Paul Nachtigall, Dr. A. Earl Murchison, Mr. James Simmons, Mr. Forrest G. Wood, Mr. Clark Bowers, and Mr. Donald McSheehy.

Many people all over the country were consulted on current and future problems of the Coast Guard and on animal systems work. Personnel in Coast Guard Headquarters, Washington, D.C., and the Headquarters of the 7th, 11th, and 12th districts gave freely of their time. Those people and their participation are referenced in the appropriate sections of this report. Project managers and scientists of other government agencies and research organizations that were consulted include Mr. Ray Nolan and Dr. Heinrich Egghand, U.S. Army Mobility Equipment Research and Development Command, Lt. Col. Daniel Craig, DOD Working Dog Center, Mr. Jerry Carp, Federal Aviation Administration, Mr. Dan Lucero and Dr. Robert Moler, Aerospace Corporation, and Dr. Dan Mitchell and Dr. Ed Dean, Southwest Research Institute. Their help was valuable in accomplishing the objectives of this project.

Dr. Peter Narins of the Biology Department, University of California, Los Angeles, was consulted on the approach to the animal capabilities survey. He gave useful suggestions on information sources.

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1.0 INTRODUCTION

1.1 BACKGROUND

The Coast Guard is engaged in a broad program of futures studies. Those studies are aimed at providing planners and decision makers with projections of the Coast Guard's operating environment, missions, and problems. Also, there are efforts to identify technologies which can be exploited for Coast Guard systems and operations in the future.

One of the technologies in which the Coast Guard has become interested is the training of birds (specifically pigeons) to assist in search operations. The pigeons, in a transparent module under an aircraft, are trained to peck a response key when they see objects which are red, orange, or yellow (e.g., life vests or rafts) on the water. As a result of that work and awareness that throughout history, animals have been used in many ways to assist man, the Coast Guard sponsored the project reported here.

1.2 OBJECTIVES AND SCOPE

The primary objectives of the investigation are to identify and determine the feasibility and the potential uses of the capabilities of animals by the Coast Guard. Consideration if given to the application of information obtained in scientific research on animals as well as actual use of animals. The focus is on the next five to twenty-five years. The project staff was urged to be creative in conceptualizing possible Coast Guard uses of biological phenomena.

Also, potential uses of animals by others with whom the Coast Guard interacts are explored. Employment of the animals for legal or illegal purposes is considered. The Coast Guard wants to know how such uses might impact its missions and what responses would be needed.

Finally, recommendations are made for a Coast Guard program to pursue research and development of the more highly evaluated system concepts. Examination and possible support of current projects being conducted by others, the undertaking of new independent efforts, and cooperative ventures with other agencies are options included in a recommended Coast Guard program.

The project does not consider biomedical uses of animals. In other words, use of animals in place of man for various kinds of testing, e.g., responses to mechanical, chemical, psychological stresses, are not within the scope of this study.

1.3 OVERVIEW

The overall study plan is depicted in Figure 2. The work initially took two parallel paths. One was to project activities in the marine environment and Coast Guard missions. The other was to learn more about the capabilities and uses of animals. Then the information from those two lines of investigation was used to formulate ways in which animal capabilities could be useful to the Coast Guard in the future.

One train of tasks involved looking at the Coast Guard's future. Several forecasts of the marine environment were studied and synthesized (block 1). The information obtained from that work is summarized in Section 2.0. Analysis of future Coast Guard roles and missions (block 2) in the projected environment are presented in Section 3.0. Much of the data which went into those analyses were gleaned from discussions with personnel at Coast Guard Headquarters in Washington and at three district headquarters.

The animal-oriented study effort involved the following tasks. The whole spectrum of animal utilization categories was identified (block 3 of Figure 2). Criteria and factors for consideration of specific uses also were discussed. That information is presented in Section 7.0.

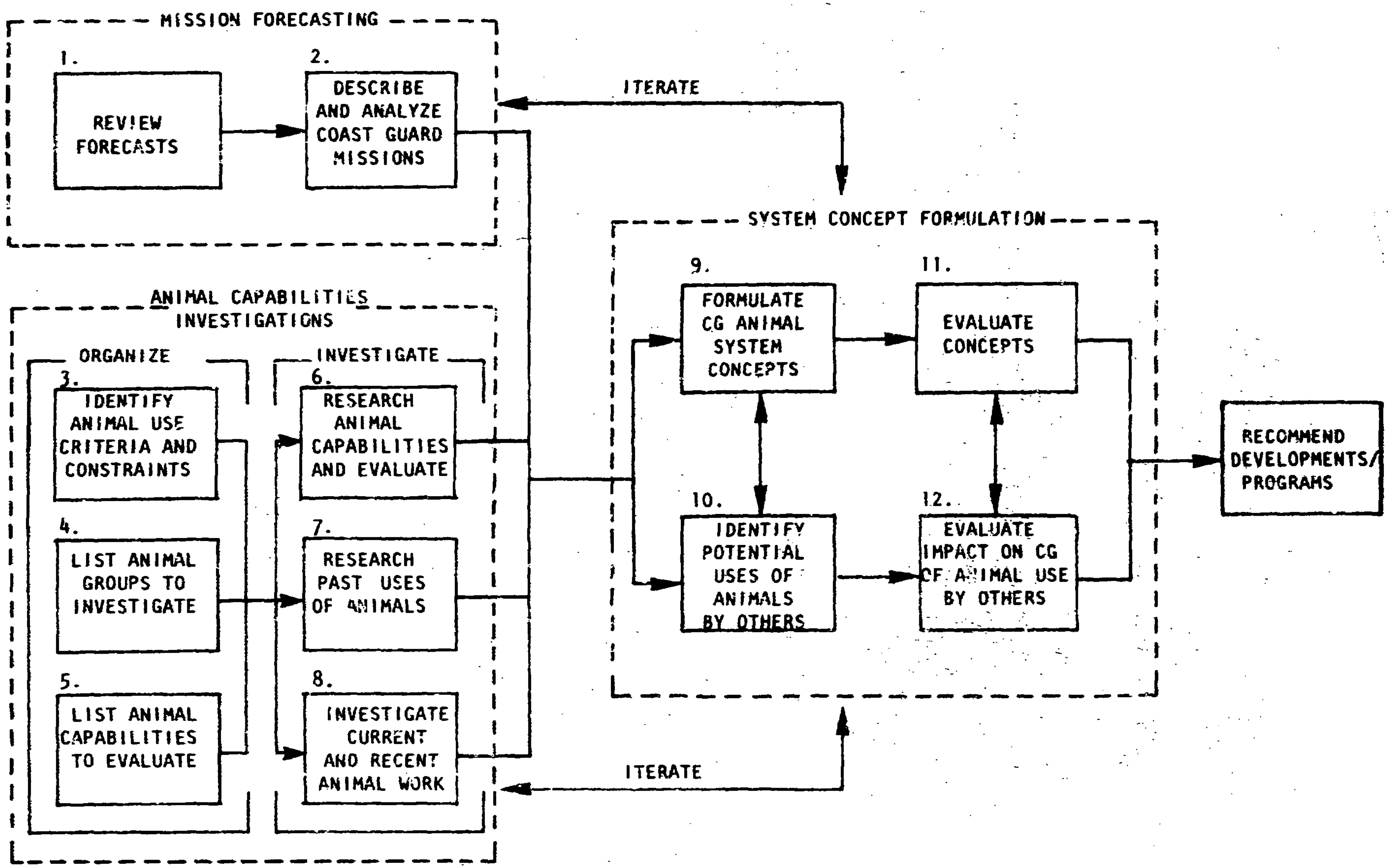

Figure 2. Overall Study Plan

Groups of animals on which to obtain capabilities data were selected from standard biological taxonomies (block 4). The types of capabilities and behavioral characteristics on which information was required were identified (block 5). Then the literature (primarily in sensory physiology) was reviewed to extract and summarize the information (block 6). The results of the animal capabilities survey are presented in Section 4.0 and the appendix.

This history of uses of animals by man was reviewed with emphasis on recent applications (block 7). That information appears in Section 5.0. Several government agencies were visited and discussions held regarding their current uses of animals. Information on current research and development was obtained (block 8). Those data are in Section 6.0.

The information from both lines of investigation was utilized to formulate a number of animal system concepts covering a broad range of Coast Guard missions (block 9). The concepts are in Section 8.0. Information and thoughts on how others who interact with the Coast Guard may use animals (block 10) are presented in Section 9.0. Evaluations of the Coast Guard system concepts (block 11) and impacts on the Coast Guard of animal uses by others (block 12) are given in part in Sections 8.0 and 9.0. Additional thoughts on the systems and uses by others also are included in Section 10.0 on recommendations for a Coast Guard program on animal systems (block 11).

2.0 REVIEW OF FORECASTS

2.1 APPROACH

2.1.1 Information Sources

In order to conceive of potential uses of animals by the Coast Guard in the future, it was necessary to get a picture of what that future might look like to the Coast Guard. In other words, what developments can be expected to occur in the world, nation, and marine environment which would influence the Coast Guard's missions and problems in performing those missions? The Coast Guard has invested in forecasting projects and the results of those efforts were made available to the staff of this project. Four documents were reviewed and analyzed.

- Commandant Instruction 5000.2B, Commandant's Long Range View, 18 July 1977
- Commandant Instruction 16014.1, Commandant's Long Range View, 22 August 1979
- Emerging Environments, Roles and Activities for the U.S. Coast Guard to 2000 A.D. by Charles W. Williams, Inc., May, 1977
- Coast Guard Forecasts by Forecasting International, Ltd., March 17, 1977

All of those documents dealt with the time period up to about the year 2000.

The Long-Range View is a Coast Guard policy document which provides guidance to Coast Guard planning staffs. While there were differences in emphasis, no basic inconsistencies were found between the two editions reviewed. The 1979 edition is a much briefer, more general document. The forecast statements in the Long-Range View draw heavily on the last two documents listed.

The Charles Williams forecast was developed by successively generating descriptions of international and national trends, marine environment trends, government roles for governing the use of the marine environment, the Coast Guard roles and activities. The probabilities of forecasted events were not estimated. Rather, the forecasts included "a set of self-consistent developments, all of which we believe will occur during the forecast period. The variations, in our view, will be more a matter of intensity and timing rather than occurrence."

Forecasting International, Ltd., generated three scenarios of the future marine environment:

- Surprise-free scenario
- High impact/low probability scenario
- High probability/low impact scenario

The surprise-free scenario incorporated the major trends and high probability/high impact (on the Coast Guard) events. The other two scenarios could potentially modify the surprise-free scenario. Several matrices and tables were presented with quantitative subjective estimates of probabilities, impacts, sub-objective weights, etc.

2.1.2 Extraction and Synthesis of Information

The following approach was taken to extract the relevant information from the forecast documents and summarize it in a way which would be useful for subsequent stages of this project. Each of the documents was studied. Next, the list of topics in Table 1 and treated under subsections 2.2 - 2.7 below was prepared. That list provided the basis for organizing the information. Statements relevant to this project, related to each

of those topics were extracted from the documents. Then the narrative summaries presented below were prepared. In most cases these summaries either use language similar to that in the source documents or are direct quotes.

The contents of Sections 2.2 to 2.7 below represent a distillation of the forecasts. Footnotes are used to indicate events or developments since the forecasts were prepared which would modify the forecasts.

2.2 OFFSHORE ACTIVITIES

There will be a steady development and utilization of marine resources within and even beyond the 200 mile limit. This will lead to a broadening of the 200 mile zone from fisheries conservation to cover additional economic and strategic interests. Oil and gas exploration will continue to dominate offshore industrial operations. However, multiple uses of the sea will lead to competition and some form of sea zoning.

Environmentalists may influence the location of offshore facilities and onshore support facilities. While there is a low probability of floating cities, there is a moderate likelihood of inhabited, permanent undersea installations. The Coast Guard, state, and local authorities will negotiate over responsibilities and jurisdictions for control of offshore facilities.

Offshore enforcement will see the largest relative growth of any operational Coast Guard program. Such enforcement covers the criminal activities treated under 2.5 below as well as economic developments discussed here.

2.2.1 Exploration of Fossil Fuel Deposits

Substantial quantities of oil and gas will be found under the sea. Offshore oil and gas development will receive growing national priority and continue to grow for at least the remainder of the century. Drilling rigs, platforms, deep water ports, and other offshore facilities will proliferate.

One forecaster predicted fourteen Atlantic Outer Continental Shelf drilling platforms with 240 oil and gas wells and seven platforms with 120 producing wells in the Gulf of Alaska by 1985. By the year 2000, between 800 and 2700 platforms were predicted on the Outer Continental Shelf of the Gulf of Mexico, California, and the Atlantic Coast.

By 1985 drilling technology will allow operations at depths exceeding 1,200 feet.* Development of petroleum resources in deeper and icy waters will shift to subsea completion systems in combination with tethered buoyant production facilities.

National policy for management of oil and gas on the Outer Continental Shelf will be updated. As oil deposits are discovered in waters of contested sovereignty, international conflicts may arise which are far more acrimonious than conflicts over fishing rights. As most rigs, platforms, and wells will be within Coast Guard jurisdiction, it may be necessary for the Coast Guard to formulate new regulations regarding safety, fire warning, security, etc. The Coast Guard may be required to provide assistance in several capacities.

2.2.2 Construction of Nuclear Power Plants

There will be a few nuclear power plants located offshore. At least one or two floating experimental plants will be under construction by the mid 80's. Possibly fifteen will be operational by the year 2000. Development of offshore plants will be spurred in part by fears of the safety of land-based nuclear generators.**

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*Current technology allows drilling at depths well in excess of that value. Exploratory drilling has been conducted at depths to 12,000 feet. Production at depths greater than 6,000 feet probably will not be performed regularly for 10 or 15 years or with current technology until oil costs exceed $60 per barrel. See discussion later on offshore assets. Reference Ocean Industry, January, 1979.

**The Three Mile Island accident has inhibited the development of land based nuclear plants. However, no surge in interest in offshore plants has been observed. Furthermore, the environmental and human safety hazards associated with offshore nuclear facilities may not be much less than those associated with shore based plants.

2.2.3 Development of Ocean Energy Resources

This category refers to the extraction of energy stored in the ocean, above it (in the form of wind) and the solar energy impinging upon it. Although they will not provide a significant percentage of the nation's energy needs, there will be at least some experimental and demonstration models of ocean energy extraction systems over the next twenty years. Energy may be extracted from or by:

- Ocean thermal energy conversion (OTEC)*
- Wave energy
- Windmills
- Solar energy collector grid
- Tidal movement
- Ocean currents
- Kelp farms**

2.2.4 Seabed Mineral Extraction

Initially, ocean mining will involve gathering ore nodules (especially manganese) from the ocean floor. Ocean mining will emerge at a slowly increasing level. More mineral deposits will be located under the sea floor. New technologies of discovering and extracting seabed resources including oil, sulphur, gold, phosphates, copper, nickel, cobalt, manganese, and other minerals will be developed. There are still legal and jurisdictional problems concerning seabed mineral extraction.

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*A pilot OTEC facility has been operating successfully off the coast of Hawaii for about a year. Futher OTEC development is planned.

**Growing algae and converting it to methane by anaerobic digestion could also be used to extract solar energy in ocean areas. A method of growing kelp on a grid in the open ocean using nutrients from upwelled water is being tried out experimentally.

2.2.5 Development of Offshore Industries

Offshore industrial and energy conversion plants will be built. Plants may be built for processing materials such as oil and high grade ores from foreign sources already traversing the seas. Some of these plants may utilize energy extracted from the ocean. Other processing plants may involve agriculture or chemical industries. New technologies will be developed for extracting magnesium and bromine from sea water.

2.2.6 Control and Management of Fisheries

There will be a higher priority given to obtaining food from the sea. The U.S. fishing fleet will grow as will the overall worldwide fishing industry. Floating factories and processing plants will be incorporated into the U.S. fleet. New fishing areas will be developed including more extensive development of fisheries in the Southern hemisphere. Gradually the fishing industry will shift from a hunting industry to more cultivation and harvesting of stocks.

More research will be devoted to obtaining food from the seas. Coast Guard vessels may help other agencies conduct acoustic surveys of fish. Capabilities will improve for monitoring fish populations and determining what levels result in overfishing. This will create requirements for allocating catches among national flags as well as individual vessels. Foreign fishing vessels may be required to carry a "black box" or transponder for positive identification and location.

2.2.7 Development of Ocean Agriculture

Technological advances will lead to greater food production from marine sources. Mariculture (of fish and shellfish) will increase. There may be some ventures offshore as well as along the coast. Inland fishing and mariculture will continue to develop. Marine plants may be cultivated as a source of protein, fuel and drugs (See 2.2.3 above). This technology will proliferate rapidly.

2.2.8 Construction of Pipelines

Pipelines may be used to connect offshore energy producing facilities with the shore.* Deepwater ports and onshore storage points or processing plants will be joined with pipelines. There may be ocean-crossing, ocean-bottom pipelines. There may also be a few vehicular tunnels on or under the seabed.

2.2.9 Construction of Deepwater Ports

Two deepwater ports will be operational in 1980. More offshore deep-water ports will be developed. Initially such ports will be built for fuel transfer from large tankers.

2.3 SHIPPING

Seabed trade and world shipping capacity will increase. Increased traffic and decreasing maneuverability of some ships will increase congestion in ports and entries to ports. Therefore, coastal, channel, and harbor pilotage requirements will become more complex. Traffic control systems will be needed.

More hazardous cargoes will be carried. There will be a greater need to prevent pollution incidents. As traffic congestion and control problems increase there will be a rise in search and rescue activities. The increasing volume of surface and air traffic and the criticality of knowing submarine locations will increase the necessity for comprehensive surveillance systems.

2.3.1 Amount of Traffic

The number of ships will increase some but not as much as the increase in tonnage of goods transported. The increased shipping capacity will partially

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*In the discussion of offshore energy production there is little attention given to how the energy would be transported to shore. Underwater cables are not discussed.

be the result of faster ships and more rapid turn around. Traffic density in U.S. ports will increase significantly due to overall projected economic growth; there will not be a shift in the proportion of marine transportation in the overall economy.

2.3.2 Variety of Ships

In general, the diversity of ships in terms of size and type will broaden. There will be an increasing number of larger ships over the next twenty years. The bulk of imported oil will be carried by ships over 150,000 DWT. Five hundred thousand DWT ships will be widely used. There may be a one million DWT tanker. The first shallow-draft supertanker will be built. Dry ore carriers in the 200-250,000 DWT class will become common. Larger, faster ships with reduced port turn around time and maintenance will help absorb increased tonnage. On the other hand, the portion of the U.S. merchant fleet between 5 and 100 net tons will increase 20% to 62,000 vessels by 1985.

The second phase of nuclear merchant shipping will be entered. Within twenty years, 20% of commercial ocean shipping may be nuclear powered.

The variety of specialized vessels will continue to grow as will size and diversity of cargoes. Specialized vessels will include LNG tankers. There may be air-cushioned freighters with chemical or nuclear power for ocean-going cargo transport. Sea-going multi-barge systems will be in use. Hovercraft will be in common use as commercial passenger and automobile ferries in many U.S. metropolitan areas.

Underwater mining submarines and cargo carriers will be introduced, possibly showing significant growth in usage during the 1990's. By 1984 it is probable that one commercial cargo submarine in the 10,000 ton class will be operating. (Previous forecasts of commercial submarines did not materialize.) Commercial deep diving submersibles will be in use. Military cargo submarines

may be developed because of the tenuous position of ocean surface transport for massive logistics support.

2.3.3 Ports and Waterways Development

Traffic density in U.S. ports will increase significantly. Foreign commerce will account for 45% of total waterborne commerce in U.S. ports. Most of the growth in domestic traffic will be between seaports and river ports. As more smaller specialized vessels are used the number of U.S. ports handling international traffic will grow. This will increase inland waterways traffic. As the U.S. exports more coal there will be a greater amount of traffic on the Mississippi, Gulf of Mexico, and the Great Lakes. Inland waterways may be used as highspeed marine highways by large numbers of commercial hovercraft.

Problems of traffic control will increase substantially in domestic waterways, coastal ports, coastal waterways and in sealanes. The greater traffic density, sensitivity to pollution potential and maneuvering room requirements of larger vessels will require restriction of access in many port areas. Greater use will be made of traffic lanes.

The approach to marine traffic management will still be to provide waterways and signs. Only when they are inadequate will guidance and control be substituted. Improvements in electronic technologies may reduce the need for audio-visual aids (buoys, lights, daymarks, fog signals). Vessel Traffic Services will be required in more ports and the degree of their sophistication will grow. Participation will be compulsory. "Airport-like" traffic control systems will be available. By the year 2000 vessel traffic control will be implemented within the 200-mile economic zone.

Trends in ship automation, specialized vessels, containerization, intermodal capabilities, and deep water ports will bring about major modifications of existing ports In addition, some new inland ports will be

developed. There will be more pressure to assure open navigability of all important waterways year round including the Great Lakes-St. Lawrence Seaway all the way to the sea and the upper reaches of the Mississippi.

2.3.4 Shipping of Hazardous Materials

Prevention, containment, dispersal, and elimination of ship-generated oil pollution will be the central concern of marine pollution control until about 1985-90. Improvements in fingerprinting oil spills will reduce the incidence of deliberate dumping. An effective, harmless technique will be developed to control accidental oil spills that are not controllable by today's techniques.

More types and increasing volumes of hazardous cargoes will be transported. There will be an increase in the number of accidents. The definition of hazardous cargoes will expand in terms of new chemical combinations, new dangers associated with greater quantities of traditional cargo, new additions to pollution risk items, and new discoveries of potential danger previously unknown or at least not acted upon.

Safe transportation requirements are in part dependent on the knowledge of the pollution burden that the environment can sustain. New concepts for "safe" and "hazardous" cargoes will emerge. Some products (e.g. dynamite) are short term hazards. Others have a slower, more insidious effect. The need for sophisticated environmental monitoring devices and techniques will increase. The entire field of commodity transportation will be subject to restrictive revisions.

Specialized vessels will be built for the carriage of hazardous materials such as liquid natural gas (LNG). For each offshore nuclear plant built, approximately 30 metric tons of fresh and 30 metric tons of spent nuclear fuel and several hundred drums of solid radioactive wastes will have to be transport annually.

The Coast Guard will be viewed as the agency with total responsibility in resolving problems of public safety in marine transport of hazardous materials. Coast Guard regulation of hazardous commodities will increase then stabilize as national policy develops.

2.3.5 Use of Containerized Cargoes

Employment of multimodal cargo containers will increase dramatically over the next ten years. Because they are sealed, inspection technology especially as related to dangerous cargo or illegal contraband must be improved.

2.3.6 Automation of Ships

There will be more automation of ships. By 1985 it is likely that 80% of the new ships greater than 2000 Gross Registered Tons will be built with centralized engine room control requiring only a minimum crew. By the year 2000, totally automated ocean shipping may be economically feasible. Use of automation will reduce crew size substantially but introduce new requirements for relieving emergency situations in the event of equipment failure.

There will be more technological advances in communications and navigation systems. More sea and air vehicles will be required to be equipped with long-range identifying equipment. Selected vessels will be required to employ more sophisticated navigation systems which will be integrated with surveillance and traffic control systems.

2.3.7 Automation/Mechanization of Cargo Handling

Automated cargo handling facilities will be installed in all major U.S. ports. This development, plus the increase in containerization, will introduce new requirements regarding inspection and control over goods flowing into and out of the U.S.

2.4 COASTAL AND INLAND WATERWAYS ACTIVITIES

Controversies over development and exploitation of marine resources and aesthetic and recreational uses of water and shorelines will grow. Issues regarding "states' rights" in inland seas and waterways will arise as waterways are more highly developed. The concept of sea zoning will begin to be applied. Among the "zones" will be oil fields, marine mines, mariculture, fishing, recreation, industrial plant use and transportation lanes. By the year 2000 permanent undersea installations may be inhabited.

2.4.1 Coastal Populations

By 1985 nearly 60% of the population will live within 50 miles of the coast. There will be a population increase of 20-25% in that area through 1990. Houseboats doubling as living and recreational units will be constructed around marinas like trailer parks. Several thousand units will be in use by the early 1980's; there could be millions by 2000. Floating cities will not be a factor in this century. However, there may be a few very small "Floating Communities" of up to several hundred families.

2.4.2 Location of Industry by the Water

New plants will continue to be located on waterside sites. (In the first quarter of 1976, 260 new plants were so located; 92 were chemical plants.)

Fresh water as a commodity will become an increasingly important issue in densely populated urban areas, cultivated irrigation areas, and more arid regions. Desalinization technologies will be developed abroad at a rapid rate throughout the early and mid 1980's. These will be selectively imported. There will be limited use of sea water as a source of fresh water for some metropolitan areas of the coastal states. Some combinations of nuclear power plants and desalinization complexes are likely on the West and possibly East Coasts.

Sea Islands could be built for special purposes such as airports.

2.4.3 On-Water Recreational Activities

More leisure time and greater affluence will lead to more recreational use of the marine environment. Ocean/coastal zone recreation expenditures are expected to reach a level of 6.5 billion dollars by 1985, a 50% increase over 1973 levels. A strong rate of growth in recreational boating is expected. There may be over 11.5 million boats in the U.S. in 1985. By 1990 there will be 30 million boat operators, 16 million boats, and 6 billion boating hours. Emphasis will shift from power to sail boats.

An increase of 6% per year is expected in search and rescue responses over a base of 20,000 as of 1977. Long term emphasis will switch from search to rescue as mean search time is reduced by various means. Coast Guard boating safety efforts will shift from on-water efforts to administration and standardization. The need to save lives will require a limited emergency medical capability.

2.4.4 Air Activity (Recreational/Business)

Air traffic passing over coastal zones will increase. Small, privately owned hovercraft or vertical take-off and landing vehicles are expected to begin emerging and show a substantial number by 1990.

2.4.5 Underwater Recreational Activities

The U.S. may have underwater parks. These could include observation ports, restaurants, promenades, monorails, and submarine tourist vessels.* Individually owned submersibles for recreational and economic use are projected to emerge rapidly during the 1980's. Some forecasters expect a form of aqua-lung permitting longer term underwater activities by individual divers to depths of 200 meters. Underwater search and rescue may become necessary.

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*Current underwater parks in the Virgin Islands, Florida Keys, and on Oahu, Hawaii do not have any underwater facilities or equipment except sign posts.

2.4.6 Exposures to Disasters

By 1990 various trends such as increased maritime traffic, greater cargo capacity of ships, transport of hazardous materials, and increased population in coastal areas will have combined to require a reappraisal of the national emergency response posture. A much higher degree of anticipatory analysis and planning will be required. The Coast Guard will continue to maintain a capability to provide disaster relief and may become involved in crisis relocation of population.

2.5 CRIMINAL THREATS

The Coast Guard can anticipate increased responsibility in dealing with terrorism and sabotage to ports, waterways, and offshore assets. The Coast Guard will have to deal with boat hijackings, acts of piracy, possession of firearms, and smuggling.

2.5.1 Tendency Toward Terrorism

As the economic use of the marine environment grows there will be increasing evidence of terrorist activities against assets in that environment. Ships as well as ports may become targets. There will be an increase in piracy. The facilities of multinational corporations may become targets. Terrorism may be employed by some third world groups.

Terrorist groups will have a variety of weapons available including chemical, biological and radioactive weapons. Nations or terrorist groups employing stolen nuclear materials may resort to nuclear blackmail or terrorism. By 1985 nuclear weapons could be sufficiently miniaturized for use by paramilitary groups.

2.5.2 Trends in Theft

There were no statements in the forecasts regarding possible changes in theft of products from shore facilities (piers, warehouses, etc.). Increased maritime commerce will present more opportunities for dockside thefts. However, containerization may make it more difficult. Thefts and hijackings of boats may increase to provide vehicles for smuggling operations.

2.5.3 Trends in Smuggling

Traffic in illegal aliens, narcotics, and contraband will grow. The Coast Guard will be more involved in interdiction and suppression of drug traffic.

Growth is seen in the volume (and possibly the variety) of international narcotics. The flow of illegal drugs entering the U.S., particularly from sources in Central and South America, can be expected to increase by 75% over 1975 levels. Since marijuana will be decriminalized for possession of small quantities in many states, this may increase demand.

The number of illegal aliens entering the U.S. will be three times 1975 levels. Control of illegal immigration via the sea will become an increasingly difficult problem.

2.6 INTERNATIONAL RELATIONS AND CONFLICTS

Development of the marine environment will cause it to become a reason for conflict.

2.6.1 Rights to Ocean Resources

The third Law of the Sea (LOS) conference will not resolve issues of economic development of the ocean. The general pattern will be for nations to declare claims on assets unilaterally or reach bi- or multilateral agreements. In time a LOS treaty will be struck giving each nation exclusive economic rights within the 200 mile zone. The Coast Guard will be the U.S. enforcement agency. If economic advantages accrue or threats seem more controllable, nations' claims to ocean areas will accelerate and extend selectively beyond the 200 mile limit.

2.6.2 Cooperation

Conflicting claims will give rise to a joint organization charged with surveillance of sensitive areas. This will follow the pattern of the International Ice Patrol and North Sea Fisheries Patrol. Establishment of international quality standards (air and water) is possible before 1990.

2.6.3 Military Threats

More potential is seen for armed conflicts because of political instabilities resulting from food, energy, and other resource scarcities. A major military confrontation could take place between the U.S. and Cuba. Given foreseeable failure of the international community to develop agreements satisfactory to more radical nations, harassment and inconveniencing of maritime commerce will occur in some coastal areas. Strong international sentiments will continue for rights of innocent passage. However, some "passage fees" may be attempted.

The oceans are changing from a protective moat to a concealment for strategic nuclear attacks. In a war, more encounters will take place between weapon systems at sea and land targets than between at-sea opponents.

The Navy's ability to protect sea lanes and coastal waters will be a fundamental security issue. The Coast Guard will be capable of performing military missions in deep ocean and coastal zones. There are conflicting trends relative to Coast Guard integration of peacetime roles with the military and Coast Guard ability to define and maintain wartime operational readiness. Means will be sought to increase the complementarity and integration of Coast Guard roles, missions, and equipment with marine defense systems.

2.7 GEOGRAPHIC REGIONS OF NEW OR INCREASED ACTIVITIES

Although there will be increased economic activity in all regions of interest to the Coast Guard, the following two are distinguished by location, size, and climatic characteristics.

2.7.1 Trust Territories of the Pacific Islands

The political situation will remain unsettled for about ten years. It is assumed that the Northern Marianas will become a commonwealth. The Trust Territories of the Pacific Islands will propose their own 200 mile limit. This will give Micronesia sovereignty over a huge area of the Pacific. The Coast Guard will be asked to give patrol and law enforcement services.

2.7.2 Polar and Northern Waters

Exploitation of natural gas and petroleum resources on the north slope and offshore will generate expanded commerce in northern waters adjacent to Alaska and Canada. Commerce will expand in the ice-laden waters of the Arctic and Antarctic. Resource exploitation will have the potential for upsetting the ecological balance in those areas.

Increased traffic, the larger economic impacts of disruption, and varying climatic conditions will make ice-breaking and other responsibilities for keeping ports open a much higher priority. Present facilities are grossly inadequate. Exploration of polar areas will be a significant area for U.S. research. Many cooperative programs in the scientific arena will require support of Coast Guard polar ice-breakers.

There may be commercial exploitation of Antarctica before the treaty is open for renegotiation in the 1980's.

Polar warfare is possible if the "wet water" ocean becomes transparent to strategic missile submarines, driving them under the ice canopy.

Underwater search and rescue in polar regions may be necessary.

3.0 ANALYSIS OF FUTURE COAST GUARD MISSIONS

The forecasts summarized in the previous section give a general picture of activities in the marine environment over the next twenty-five years. In this section selected aspects of the future marine environment and Coast Guard missions are described and analyzed. This will provide a better foundation for formulating biologically based system concepts for possible development by the Coast Guard.

First, a set of Coast Guard roles and missions were defined. Then a group judgment process, described later, was used to identify those forecast topics which would have the greatest impact on future Coast Guard missions. Topics of particular interest in this study were selected for further investigation. Finally, the selected forecast topics and the Coast Guard operations impacted by those forecasted marine activities were analyzed.

3.1 COAST GUARD ROLES AND MISSIONS

Coast Guard roles and missions are categorized and defined below. This particular categorization scheme was chosen because of its potential usefulness in this study. For that reason the planning, specification, and regulation functions (in which it seemed inappropriate to have animals participate) were left out of the definitions of the missions. For purposes of conciseness and brevity, phrases rather than complete sentences are used sometimes to define the mission.

3.1.1 Traffic Flow Facilitation and Control

Performance of this role will fulfill the Coast Guard Objective B - "To facilitate waterborne activity in support of national economic, scientific, defense, and social needs." Other objectives relating to safety and environmental protection will be supported.

3.1.1.1 Traffic Control. Real time directing and control of traffic to facilitate movement of shipping and prevent collisions or groundings. Enforcing traffic rules also is included.

3.1.1.2 Aiding Navigation. Deployment, operation, and upkeep of navigation aids to assist vessels in knowing their locations, plotting their courses, following traffic control directions, and avoiding hazards.

3.1.1.3 Ice Operations. Forecasting, monitoring, warning of, and breaking ice.

3.1.2 Safety and Emergency Operations

The Coast Guard has an important and traditional role in preventing and responding to maritime accidents. This role specifically supports the Coast Guard's primary objectives - "To minimize loss of life, personal injury, and property damage on, over, and under the high seas and waters subject to United States jurisdiction."

3.1.2.1 Inspections. Conduct of inspections to insure that vessels are structurally sound, that safety regulations are being followed, and that hazardous conditions which could cause an emergency do not exist on ships or waterfront facilities.

3.1.2.2 Surface Search and Rescue. All Coast Guard activities relating to finding and rescuing people in the water or lifeboat/rafts. The mission includes finding and rescuing people in boats/ships with which communications have been lost. This mission is distinguished from the fourth mission which does not require search.

3.1.2.3 Underwater Rescue. Finding and rescuing people believed to be alive but stranded or in distress in underwater diving equipment, submersibles, or habitats. Search also is an important aspect of this mission.

3.1.2.4 Aiding Vessels/Structures in Distress. Aiding vessels, platforms, or waterfront structures on fire, breaking up, foundering, dead in the water, or otherwise in jeopardy.

3.1.3 Underwater Investigation and Recovery

This role relates to and is a potential follow-up to several other missions. The role includes finding, examining, and possibly recovering vessels, bodies, equipment or other objects from underwater. Performance of this role might follow the sinking of a vessel, the accidental or intentional disposal of a package, e.g., to conceal criminal activity, or failure of underwater equipment.

3.1.3.1 Vessel/Structure Inspection. Inspection of sunken vessels to investigate causes of accidents, extent of damage or contents. Examination of platforms, pipelines, or bottom mounted equipment to determine condition. Could include work to facilitate raising to the surface.

3.1.3.2 Body Search and Recovery. Finding and recovering bodies of divers, swimmers, victims of waterfront, shipping, boating, aircraft or undersea vehicle or habitat accidents.

3.1.3.3 Package/Equipment Recovery. Finding and recovery of equipment lost or intentionally dropped into the water and sunk.

3.1.4 Law Enforcement and Security

The Coast Guard has an important role in protecting people, vessels, structures, property, equipment, and natural resources from criminal activities. The areas of concern are the maritime environment, coastal areas, ports, and inland waterways of the United States. This role supports Coast Guard Objective D, the safety and security objective.

3.1.4.1 Smuggling Control. Interdiction of smuggled illegal or controlled items into or out of the United States including: illegal aliens, narcotics, arms, nuclear material, etc.

3.1.4.2 Theft Control. Dealing with piracy, hijacking of vessels, stealing materials from shore facilities, and poaching in fisheries, aquaculture, or ocean floor mineral deposits.

3.1.4.3 Terrorism Control. Deterrence, detection, and response to terrorist activities in the marine environment. Those activities may be in the form of destruction of assets and taking lives, holding personnel, vessels or property as hostages to negot'ate for demands, interference with operations, or sabotage.

3.1.4.4 Regulating Use of Marine Resources. Controlling authorized operations to insure that legal bounds are not exceeded. For example, the size of the catch of certain fish may be regulated and the Coast Guard may be requested to help enforce that regulation.

3.1.5 Environmental Protection

The Coast Guard has a major role in implementing the country's policy of protecting the marine environment.

3.1.5.1 Monitoring and Surveillance. Determining when and where a pollution incident has occurred, its nature and magnitude. For the most part the Coast Guard will be concerned with discrete incidents, such as a spill, rather than a gradual build-up of pollutants.

3.1.5.2 Incident Control. Control of spills, leaks, and incidents to minimize the effects on the environment.

3.1.5.3 Investigation. Finding out who was responsible for the occurrence of an environmental incident. The causes of the incident as well as the sources of pollutants must be determined not only to assign responsibility, but to determine ways of preventing problems.

3.1.6 Military Operations

The Coast Guard performs military duties as a specialized service in the Navy in times of war or during peacetime in case of natural disaster or domestic emergency. The missions listed below were chosen as potentially assignable to the Coast Guard because they involve areas in which the Coast Guard normally operates.

3.1.6.1 Defense Against Swimmer Attack. An enemy may covertly transport swimmers or swimmer delivery vehicles to the vicinity of U.S. ports where they could enter and attack ships and port facilities. The mission is detection and neutralization of such threats.

3.1.6.2 Protection Against Landings. Interdiction of agents, commandoes, or special force units attempting to land on the shore of the U.S. The mission could also be conducted in support of an ally.

3.1.6.3 Protection of Offshore Assets. Defense of offshore energy, fishing, industrial, mineral or military facilities.

3.1.6.4 Mine Countermeasures. Detection, marking and clearance of mines planted in offshore waters, ports, or inland waterways.

3.1.6.5 Ocean Surveillance. Maintaining surveillance of U.S. Coastal areas (surface, undersea, and air space).

3.1.6.6 Explosives Loading/Unloading Supervision. Assuring the safe transfer of ordnance from one transport mode to another and in and out of storage at ports.

3.1.6.7 Natural Disaster and Domestic Emergency Operations. Relief services to communities on or near coastlines or waterways in case of disaster caused by hurricanes, floods, earthquakes, tsunamis, or explosions. Includes providing supplies, supporting evacuation, warning populations, search and rescue, body searches, etc.

3.1.7 Support

Performance of these missions enables the Coast Guard to conduct its operational and regulatory missions. Only the support missions which may have a bearing on this study are included (e.g., legal, financial, etc., are excluded).

3.1.7.1 Communications. Provisions of communications to support all Coast Guard missions including potential new underwater missions. The communication system also supports the needs of the maritime community, especially in distress freqency bands and maritime mobile calling bands.

3.1.7.2 Intelligence and Security. Obtaining and evaluating information to support primary missions of the Coast Guard. Prevention and investigation of theft, pilferage and destruction of Coast Guard assets by personnel within the service. (External threats are covered under Law Enforcement and Security.) Protection of classified material.

3.1.7.3 Maintenance. Keeping Coast Guard ships, aircraft, land vehicles, equipment, and facilities in condition to perform primary missions.

3.1.7.4 Science Support. Providing logistics and vehicular support to scientific expeditions. Collecting data in support of scientific studies.

3.1.7.5 Public Relations. The nature of several Coast Guard missions requires that a variety of publics (e.g. boaters, fisherman, shipping companies, etc.) be aware of, understand and respond to Service regulatory, humanitarian, and enforcement programs. This mission endeavors to promote such public relations.

3.1.7.6 International Relations. Promoting good relations with other countries and supporting U.S. policy with those countries. Training of foreign personnel, demonstration of U.S. Coast Guard techniques and equipment, and participating in cooperative programs with other countries.

3.2 INFLUENCE OF FORECASTS ON COAST GUARD MISSIONS

A set of judgments was obtained and utilized to help focus analyses on those Coast Guard missions which would be most impacted by predicted changes in maritime activities. The data collection, analysis procedures, and the results are described below.

3.2.1 Data Collection and Analysis Procedures

A matrix of 900 cells was prepared by listing the forecast topics from Section 2.0 down the sides as row titles and writing the missions defined in Section 3.1 across the top as column headings. A group of nine people were asked to rate the impact of each forecast on each mission. Seven of the judges were R & D personnel from Coast Guard Headquarters, one judge was the project manager from the Naval Ocean Systems Center, and another was the lead author of this report.

A rating scale from 1 to 5 was used. A rating of 5 meant that the forecast for a particular topic would significantly increase or change the nature of Coast Guard operations with respect to the specific mission considered. A rating of 1 indicated a reduction negligible change in Coast Guard operations.

Each judge's ratings were normalized to correct for the different rating tendencies (such as leniency) of the judges. Then the normalized ratings were averaged across judges and the averages converted back to the original rating scale values. The resulting scale values are shown in Figure 3.

To make the figure easier to interpret, the scale values then were divided into four groups and coded as shown in Table 1 below.

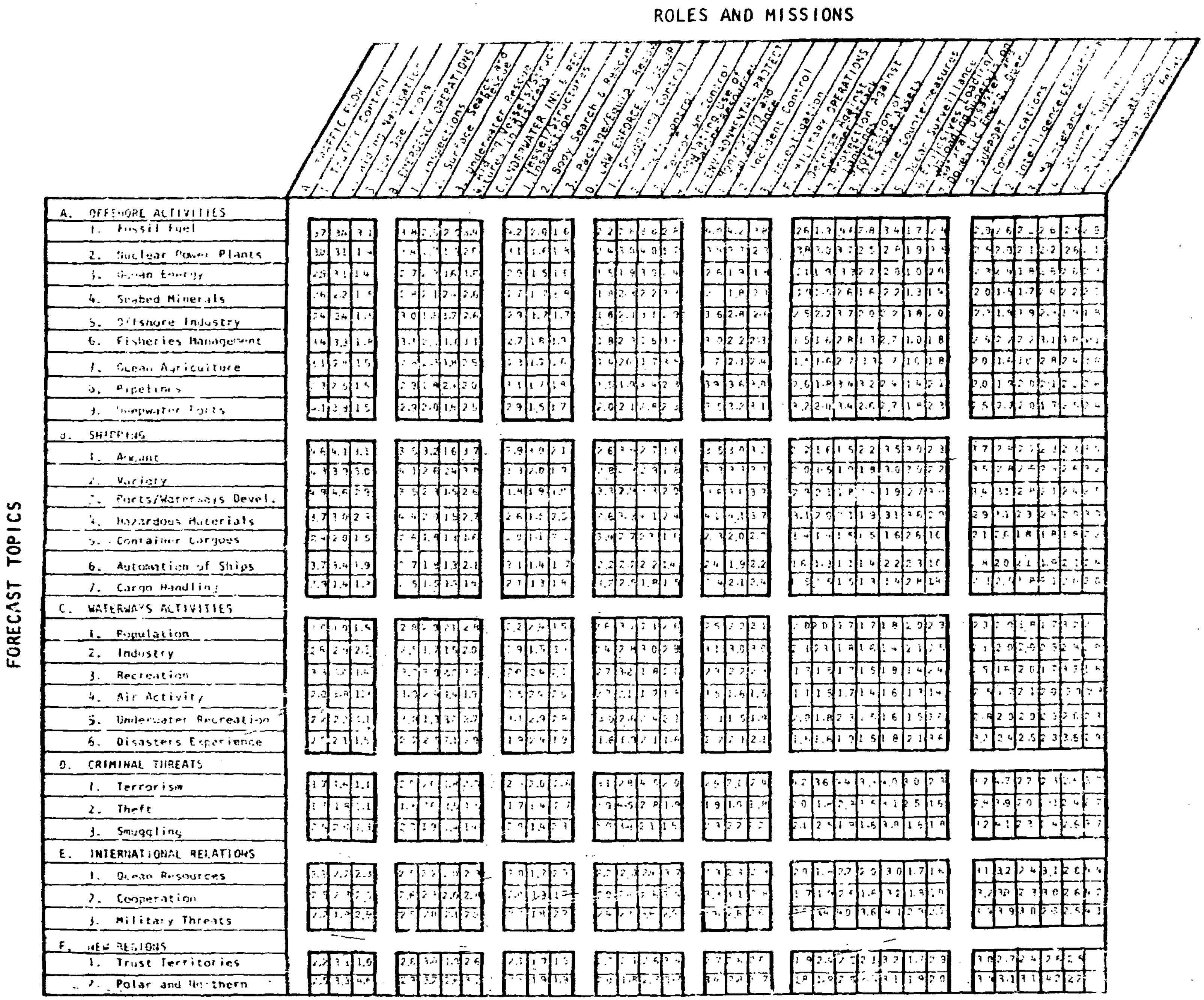

Figure 3. Scaled Judgments of the Impact of the Forecasts on Coast Guard Roles and Missions (1.0 low to 5.0 high).

Table 1. Coding of Matrix.

Cell Scale Values	% of Cells	Code	Meaning
0 - 1.7	21%	Blank	Negligible impact of forecast on mission or decrease in mission demands
1.8 - 2.5	45%	Dots	↓
2.6 - 3.1	21%	Stripes	↓
3.2 - 5.0	13%	Black	High impact of forecast on mission.

3.2.2 General Assessment of Forecast-Mission Relationships

By looking at the pattern of codings in Figure 4, one can identify general groupings (numbered by areas in Figure 5) of forecasts and missions which are either highly related or relatively unrelated to each other. Figures 4 and 5 were studied in great detail and used to stimulate ideas for the system concepts presented later in this report. The darkly outlined shaded areas in Figure 5 are high impact areas; the unshaded outlined areas indicated low impact of the forecasts on the missions. Both within and outside of those relatively broad areas are individual mission/forecast relationships which are important (e.g., forecasts A1-9 relations to mission C1).

Let us look first at those areas coded predominantly black and striped. It can be seen that the Coast Guard's role of facilitating the flow of traffic by means of traffic control and use of navigation aids will be seriously affected by predicted increases in offshore activities, shipping, and some trends along waterways (region 1 in Figure 5). Some of the safety and emergency operations are also heavily influenced by the same forecasts (region 2). Vessels and port inspections and aiding vessels/structures in distress are missions which will be most affected. It is predicted that the surface search and rescue mission will be impacted greatly by increases

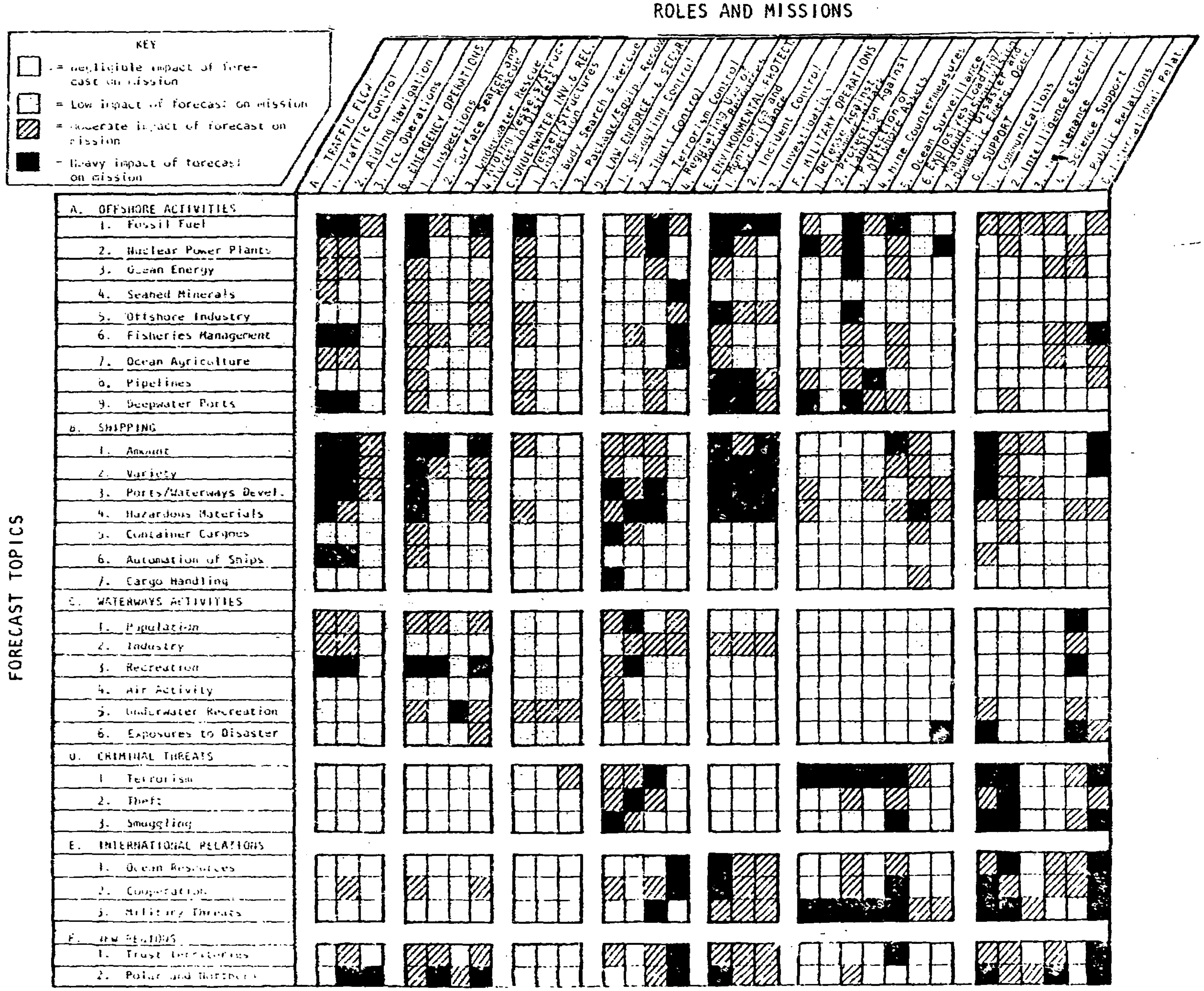

Figure 4. Groupings of Scaled Judgments (From Figure 3) of Forecast Impacts on Roles and Missions

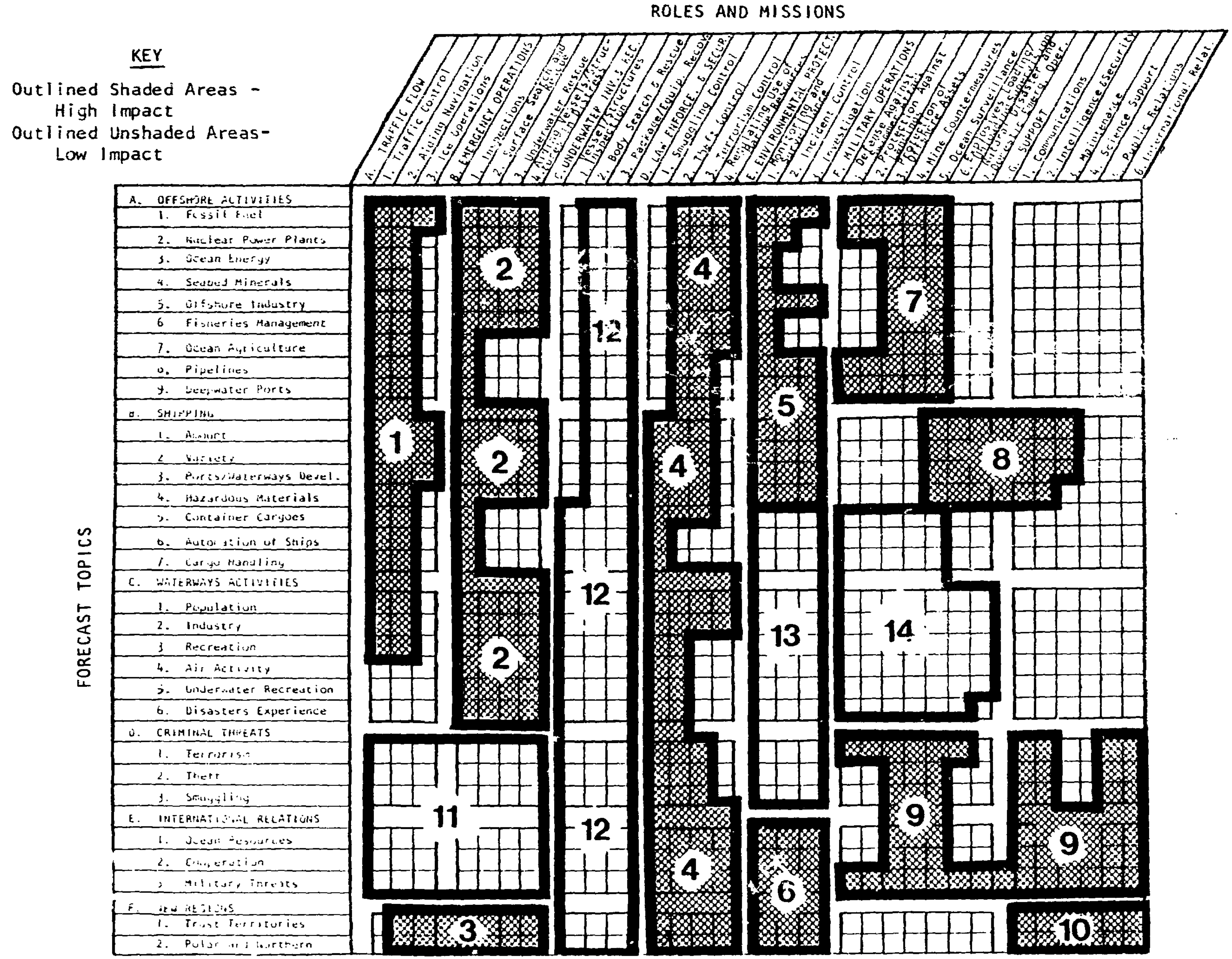

Figure 5. General Areas of High and Low Impacts of Forecasts on Missions.

in the amount and variety of shipping and recreational boating(2). Developments in "new regions," especially polar and northern waters, also will add to Coast Guard traffic flow facilitation and safety and emergency operations responsibilities (3).

Demands on the law enforcement missions will be increased selectively by most of the forecasts (4). Predicted changes in the amount and nature of shipping and selected offshore activities will have a heavy impact on the environmental protection missions (5). Those missions also will be affected by the forecasts of international relations and activities in new regions (6).

Military operations will be affected selectively by the increase in offshore activities (7). Increases in shipping will impact other military and some support operations (8). Some criminal threats and predictions of changes in international relations will affect military operations and support missions (9). Support requirements will also be increased by developments in "new regions" (10).

There are several areas on the figure, predominantly dotted and blank, in which forecasted trends will have little influence on certain Coast Guard roles. Projected criminal threats and trends in international relations will have little influence on traffic flow and emergency operations missions(11). With few exceptions (some need for sunken vessel/structure inspection), the forecasts do not place much demand on the Coast Guard for underwater investigation and recovery operations (12). However, it should be noted that other missions, e.g., terrorism control, might benefit from underwater operations capabilities. Environmental protection mission requirements are not augmented much by the way ships and cargoes will be handled, by development of waterways (with the exception of increased industrial activity) or forecasted increases in criminal threats (13). Military operations are not affected by ship and cargo handling or by development of the waterways (14).

Selected forecast topics and Coast Guard missions are analyzed in Sections 3.3-3.10. They were chosen for greater depth of analysis for the following reasons:

- Their importance as indicated by the analysis of the matrix
- Potential promise of biological systems to aid in mission performance
- The need for more detailed information than is provided by the matrix in order to formulate viable system concepts.

3.3 TERRORISM THREAT TO OFFSHORE ASSETS

It has been predicted that terrorism will be employed by alienated groups within and outside the U.S. The development of valuable economic assets offshore is providing many new targets for terrorists. However, the attractiveness of those targets relative to urban, onshore industrial, or aircraft targets is questionable. For some years terrorists will find a greater selection of diversified targets in high population and industrial areas on shore. On the other hand, some offshore assets may be targeted because of political significance, ownership, or value or to achieve a special effect.

Three types of terrorist activities need to be considered:

- Taking over and holding an asset for ransom
- Damaging or destroying an asset without prior warning
- Damaging or destroying the target with advanced notice given (possibly after an explosive has been set, but not yet detonated).

The distinction among these activities is important because they require somewhat different responses on the part of the Coast Guard. Deterrence, detection, and interception of the threat may be considered for use against all three activities. Once an asset has been taken over by terrorists and is being held to negotiate for demands, different responses are required

e.g., a rapid deployable strike force or SWAT team. If a bomb threat is received, above and underwater search capability may be required. Likewise, if a bomb has destroyed or damaged a marine asset, an underwater investigative capability may be required.

Keeping the points discussed above in mind, each of the major types of offshore assets will be described as potential targets of terrorist attack.

3.3.1 Fossil Fuel Exploration and Production Facilities

3.3.1.1 Description of Assets. The development of offshore oil and gas exploration and production facilities will provide several types of targets for terrorists. Of those targets, the most obvious are the drilling rigs. U.S. well drilling facilities can be divided into five basic categories of rigs, one a fixed installation while the rest are mobile. The fixed platform represents the overwhelming majority of offshore well structures in the U.S. to date. They are used both for drilling and the production phase of a well. By 1990 a maximum depth of 1500 feet is expected for fixed platforms.[1]

The four mobile types of their expected numbers in U.S. waters in 1980 are:

- Submersible rig (23)
- Drillship or drillbarge (19)
- Semi-submersible rig (28)
- Jack-up rig (115)

Of these, over 156 will be operating in the Gulf of Mexico. While primarily intended for drilling, mobile rigs are often used for initial production to establish early cash flow from a well. A typical mobile rig may be greater than 300 feet on each side with a derrick about 140 feet tall. The mean water performance depth of these rigs vary from 56 feet for submersible and 210 feet for jack-up rigs to over 100 feet for semi-submersible

rigs and 1400 feet for drill ships. As mentioned previously, exploratory drilling has been performed at depths over 12,000 feet. However, it is estimated that the bulk of the drilling during the next 10 years will be in water depths of 600 feet or less for economic reasons.[2]

When oil or gas - or both - are found in commercially significant quantities, preparations are made to change the platform from drilling to production operations. This involves drill hole preparations, installation of safety devices and the installation of the wellhead assembly ("Christmas tree") which is a series of valves, controls and connections designed to regulate the flow of fluids from the well. More elaborate subsea systems can receive gas and/or oil from individual wells, commingle it and deliver it to a surface facility. Once the production equipment is installed, the mobile drilling platform may be removed and nothing left showing on the surface (depending upon the shipment method). The average depth for the subsea completion in U.S. waters is about 147 feet.[3] Some 100 producing areas are off the Southern California Coast and in the Gulf of Mexico.

Pipelines are generally used to transport oil or gas to onshore facilities for processing or transhipment to refineries. These pipelines are weighted and, by government regulations, buried in the seabed, where water depth is 200 feet or less. Pipelines begin at crude oil or natural gas producing fields, where there may be one or more wells (one to thirty or more) or production platforms. Production from several completion systems is often collected by small gathering lines and moved ashore in a single stream through a larger mainline. In general, the pipelines consist of long sections of high-quality steel pipe, from two inches to several feet in diameter, welded together in one continuous string. Pressure pumps and compressors are placed along the line at appropriate distances to maintain a constant flow. In addition, valves, regulators, and other specialized devices control the stream and pressure in the line, or shut it down completely if required.

In the mid-1970's the world's depth record for offshore pipeline was held by a 32 inch pipeline installed in 480 feet of water. By 1976, the record water depth was over 1100 feet and now lines are being considered for depths of 2500 to 3000 feet.[4] More than 7000 miles of submarine pipelines now trace their way through U.S. waters.[5]

Floating storage and/or production platforms are important alternatives to pipelines and subsea production systems. These alternatives are becoming increasingly important as ocean depths become greater. The floating platforms are currently being used as mooring terminals which can deliver fluids directly to shuttle tankers.

3.3.1.2 Vulnerabilities. An oil rig could be boarded and taken over by terrorists who approach in small boats or possibly submersibles. Once on the platform they could capture the crew to hold hostage. The terrorists would probably plant explosives and threaten to destroy the rig if they were attacked. Explosive charges might be placed below the water on the platform legs or wellhead assembly. The rig could be held while demands are negotiated.

Alternatively, the terrorists might attack the rig, blow it up, and withdraw quickly. If the terrorists are intent on destroying the rig rather than holding it as an implement for negotiations, they may attempt to approach covertly, plant charges for timed or command detonation later, and depart undetected. Because oil rigs have helicopter landing pads, a sophisticated group could make an airborne attack. Another way of destroying or heavily damaging a rig would be to ram it with a hijacked merchant ship.

Terrorists equipped with scuba gear or submersibles could attach charges to the Christmas trees of producing wells. The floating storage and production platforms would be even easier targets because attacking those facilities would not necessarily require the diving gear and diving support needed to attack subsurface production equipment. Shuttle tankers moored to production platforms or transfer buoys are also vulnerable to terrorist sappers.

It would be possible for terrorists using submersibles or scuba gear to dive, locate, and blow up pipelines. However, locating and getting to buried pipelines may present them with problems. It might be easier to attack where the pipeline comes ashore. Pipeline control stations, fuel storage, or processing plants along the shore could be targeted. Pipelines in deeper water (>200 feet) might not be buried. They could be ruptured by dragging special grapnels or exploding line charges across them.

3.3.1.3 Defense Problems. If the threat to oil or gas drilling rigs materializes it will be extremely difficult for the Coast Guard to protect each platform individually. There are currently over five hundred rigs in U.S. waters, the overwhelming number of which are currently in the Gulf of Mexico. Over time, the number, geographic spread, and distance from shore of the rigs will increase. Each rig should be protected by its own security force with appropriate sensors and weaponry. What the Coast Guard could provide is:

- Overall intelligence, patrol and surveillance
- A quick response force to go to the aid of platforms under attack
- The capability to search for explosives on both the exposed and underwater portions of the rigs
- Guidance on security systems and procedures
- Skilled negotiators

Large floating production and transfer platforms with moored shuttle tankers might be protected like rigs by onboard security systems.

The number and distribution of wells and pipelines works against point defense of these facilities. Areas might be patrolled and a rapidly deployable underwater search, investigative, and damage control capability would be useful if a warning were received or damage inflicted.

3.3.2 Power Plants

Three types of offshore power plants need to be considered:

- Nuclear
- Ocean thermal energy conversion (OTEC)
- Wave energy extraction

The first two would probably be centralized facilities with all equipment located on a single platform. Wave energy power plants would have many power generating stations. One system proposed by Lockheed would produce one to two megawatts for each 250 foot diameter generating unit, most of which is below the surface of the water. Because of the number of individual units in a wave energy power system, it does not appear to be an attractive target.

There will not be many offshore nuclear or OTEC plants and each will be of sufficient size and importance to warrant its own onboard security system. Defense against surface or underwater attack may be necessary. On an OTEC plant the large pipe that draws cold water up from ocean depths could be attacked. Floating nuclear power plants also may have some water intakes which are vulnerable. One would expect the platforms to be sufficiently compartmentalized so as to be difficult to sink. Surveillance and patrols of the waters around all offshore power plants might be worthwhile.

The forecasts do not discuss how power would be brought to shore. Most likely an underwater power cable would be utilized. Depending on its depth and whether or not it were buried in the seabed, the cable may or may not be of interest to terrorists.

3.3.3 Offshore Industry

Floating oil refineries, chemical plants or other offshore industries would not appear to be any more vulnerable or attractive to terrorists than their onshore counterparts. If any are targeted, the attackers would most

likely approach by small boat or possibly as swimmers from a nearby boat. Again an onboard security system with sensors to detect approaching vessels and intruders would be warranted.

3.3.4 Aquaculture.

Offshore fish farms would have moored or dynamically positioned netted areas or racks containing a high density of cultured fin or shell fish. A support platform and possibly a processing plant would be connected to the farm. It has been suggested that fixed oil rig platforms being utilized for oil production might serve as bases for maricultures. Also there may be maricultures associated with OTEC facilities since the cold water upwelled by an OTEC plant is rich in nutrients. Those nutrients can be used to culture organisms low on the food chain to be used as feed for higher level organisms in a polyculture.

If, for some reason, terrorists choose to attack a fish farm, the support facility or processing plant would be most vulnerable to takeover or destruction by armed attack or use of explosives. Netted areas could be ripped open or sunk.

Kelp farms could cover hundreds of thousands of acres. Experimental work is continuing on such farms to raise kelp for conversion to methane and possibly liquid fuels. As the grid supporting the plants would be so extensive and submerged, it might not be susceptible to catastrophic damage from terrorists. Several elements of the mooring or dynamic positioning system could be destroyed with disastrous effects to the grid. The floating support facility would be about as vulnerable as other platforms discussed.

3.3.5 Seabed Mineral Extraction

The only offshore asset involved in mining manganese nodules are the dredging ships. Only their slow speed would make them more vulnerable than other ships to boarding and takeover by terrorists.

3.3.6 Off-Shore Ports

A terrorist group could land and take control of an off-shore port. Alternatively swimmers or people in submersibles dropped off by boats could approach a large tanker moored at a port and plant charges on it. Since there will be a limited amount of specialized traffic to an off-shore port, a sensor system and patrols might be effective in detecting intruders. There will be few enough of these ports that the Coast Guard might be able to have a dedicated security force at each.

3.3.7 Summary

Offshore oil rigs, floating production platforms and loading terminals are high value assets which would be relatively easy for terrorists to take over or destroy. The large number of rigs and their distribution makes them difficult to defend. Undersea oil and gas production facilities are extensive. Sabotaging well heads or pipelines would require diving equipment training and support which could be obtained by sophisticated, well-financed groups.

Offshore nuclear and OTEC power plants will be few and each could have a sophisticated security system associated with it. The same holds true for offshore ports. Power transmission cables from offshore power plants will be vulnerable to sophisticated terrorist groups unless they are well-buried in the seabed or in deep waters.

Support platforms for ocean industry and aquacultures have the same vulnerabilities as other offshore platforms. Fish enclosures and plant support grids in aquacultures could be torn up, but that might be too time-consuming an operation for a terrorist attack. Ocean mining ships are only more vulnerable than other ships because of their slow speed.

The following table represents general categories of offshore developments and terrorism control measures appropriate to each:

Type of Asset	Terrorist Control Measures
• Numerous high value surface assets, e.g. oil rigs	• Sensor system and small onboard security force • Substantial quick response force available (including underwater inspection capability)
• Extensive high value subsurface assets, e.g. well heads and pipelines	• Area surveillance and patrols
• Few very high value critical surface platforms, e.g. nuclear power plants	• Local surveillance and patrols • Substantial onboard sensor system and security forces (including underwater inspection)
• Areas	• Substantial quick response force available
• Areas of generally high off shore activity	• Intelligence, surveillance, patrols, quick reaction response force (including underwater inspection)

The key questions are whether or not:

- Terrorist activities in the United States will increase
- Such activities will be directed against economic assets or people.
- Offshore developments will start to attract more attention from terrorists than counterpart assets on land

It should be noted that at some level of escalation, terrorism could become such a threat to vital economic and security interests of the country that the response would resemble a military operation more than law enforcement.

3.4 TERRORISM THREAT TO SHIPPING

A few characteristics of future shipping have implications for the terrorist threat. They are:

- Larger ships
- Hazardous cargoes
- Automation with associated smaller crews

The first two characteristics might make ships tempting targets for terrorists. The take over and threat of destroying a supertanker with its hazardous cargo of significant economic value could pose a powerful bargaining tool. A very large tanker and its cargo are worth over 100 million dollars. Forcing the crew to ground such a vessel could create severe environmental damage. Blowing up a tanker loaded with certain chemicals in port could cause massive destruction and loss of life.

The smaller crew of an automated ship would make it easier to take over. A ship might be boarded at sea from a boat either by threatening to fire upon it or by covertly drawing alongside and boarding with or without the support of dissident crewmen. In port prior to unloading or just after loading,a ship could be forcefully boarded from the accomodation ladders or covertly by swimmers or from a boat.

Another possibility is an attack on a foreign ship in a U.S. port by a group with grievances against that particular foreign country or U.S. relations with it. Such an incident could be both embarrassing to the U.S. and have severe effects on international relations.

Similarly, cruise ships could prove to be attractive targets for terrorists. Because of the number of lives involved, hijacking or bomb threats to cruise ships bear some similarity to such acts against commercial aircraft. About one dozen foreign flag cruise vessels use Miami as a home port for cruises to the Caribbean.[6]

3.5 TERRORISM THREAT ALONG WATERWAYS

If terrorism is ever directed toward industrial targets in this country and more industry is located along waterways, then, of course, terrorist attacks along waterways can be expected. A ship sunk at a selected location could block all commercial traffic on a waterways. However, there are few other reasons why terrorist attacks along waterways should be expected more than against inland targets. One is that in some situations a waterway might provide a covert escape route. A terrorist might be able to slip into the water at night and escape under cover of darkness easier than he could by land vehicle.

3.6 SMUGGLING[7]

Smuggling contraband into or out of the country takes place on all sizes of ships and aircraft. The vessels' primary purpose may be smuggling or the illegal goods may be stashed on board without knowledge of the ship operators, either carried by a passenger or crewman or as falsely labeled cargo.

The forecasts indicated growth in smuggling of narcotics, arms and explosives, and aliens. This will place a greater burden on the Coast Guard which already utilizes a substantial portion of its resources in efforts to control smuggling.

3.6.1 Control Functions and Problems

Analysis of the smuggling control mission reveals the following functions which are performed. The first is obtaining intelligence about contraband shipments, vessels' speed, their routes, and times of departure or arrival. This function is performed by other agencies which provide the Coast Guard with information. The second function is maintaining overall surveillance and patrol of shipment routes to detect vessels which are likely carriers of contraband. In certain ocean areas patrol may be facilitated by choke points which concentrate traffic, e.g., gaps between islands in the Caribbean.

The third function is critical. It is determining which of many vessels detected should be searched. Since boarding and searching a vessel is so time consuming and can have effects on public and international relations (if a foreign vessel is searched), it is important to have an efficient method of selecting vessels to search. Of course, if there is a tip (from performance of the intelligence function) that a vessel is carrying contraband, when that vessel is spotted, a search is warranted. Observation of a ship rendezvousing with a boat is a cue that a transfer of contraband may be taking place. Sometimes high speed boats take narcotics from a larger vessel into shore. Other unusual behaviors, such as loitering in an area or running at night without lights, arouses suspicion. Any boat identified as stolen would be stopped. However, a stolen boat probably would have been refitted to modify its appearance. In fact, there have been few positive connections made between boat theft and smuggling. Finally, it may be possible to sense externally if a boat is carrying certain substances. Notably, unless carefully wrapped, quantities of marijuana might be detected by their odor.

When a Coast Guard boat approaches a vessel to perform a search, if there are illegal goods on board, an effort may be made to dispose of them by either throwing them overboard to scuttling the ship. In either case, it would be desirable to have the capability to recover some of the goods as evidence to use in criminal prosecution.

Once a vessel is boarded, the search function begins. Often, unless there is good evidence that controlled items are on board, all that is done is a document check. The main beam number is compared to that on the ship's papers. The cargo manifest is checked against cargo containers. If a ship's primary cargo is marijuana, it might not be too difficult to find. Explosives or firearms packed with Cosmoline could possibly be located by a sensitive odor detection device. Carefully sealed in plastic and hidden among other cargo on a large ship, marijuana might be hard to locate. The

harder drugs, such as heroin or cocaine, because of their value and potency, are shipped in smaller quantities, will generally be well wrapped, and can be concealed more easily. There are many places on a ship or boat in which to hide packages of hard drugs. Narcotics, firearms, or explosives may be placed in sealed containers or other types of boxes, innocently labeled, and appear on the cargo manifest as different items. Unless intelligence has provided good information on how the contraband is being shipped or there is a way of sensing the illicit items from outside of the containers, the time and cost of a thorough search may be prohibitive.

Finally, contraband might be detected by surveillance of off-loading points. Bales of marijuana might be unloaded at night at little used out-of-the-way landings. Some areas of the country, e.g., the gulf states, have many such landings. The Southern California coast does not.

Contraband shipped in innocent looking, falsely labeled containers can be delivered as ordinary cargo in regular ports. A crewman or passenger can easily leave a freighter, fishing boat, or pleasure craft concealing a package of hard drugs at a commercial port or marina.

The above discussion focuses on the problems and functions performed to control smuggling, especially of narcotics, into the U.S. Similar problems are faced in attempting to restrict the flow of arms and illegal aliens. Aliens often try to enter the country in boats which may be overloaded. The refugees may be starving or suffering from exposure. Sometimes they are dropped off by boats offshore to swim ashore. While the flow of narcotics and aliens is into the country, it is anticipated that the movement of arms out of the country will be greater than shipments into the U.S.

3.6.2 SUMMARY

In summary, one of the major needs of the Coast Guard to do a better job of coping with increased levels of smuggling is better systems for determining if contraband is on vessels which have been boarded. It would

also be desirable to have means for detecting the presence of illegal goods on a ship prior to boarding. It is possible that marijuana could be detected at a distance, but better packaging might negate the effectiveness of any such system. Furthermore, control of hard drugs may be of greater importance in the future. Of course, improved intelligence would be desirable to have a system which could recover packages of contraband thrown overboard or in scuttled vessels.

3.7 SEARCH AND RESCUE (SAR)

Analysis of the search and rescue mission is particularly interesting with respect to this project because the Coast Guard is already sponsoring development of an animal sensor system to aid in search operations (see Section 6.4.1). The Coast Guard Search and Rescue statistics for 1978 excerpt below give a picture of the frequency of different types of calls for assistance and of the resources and time utilized in responding to those calls.[8] Discussions with Coast Guard personnel in headquarters, Washington, D.C. and from the 7th, 11th, and 12th district headquarters also yielded valuable information.[9]

3.7.1 Breakdown of Assistance Calls

In 1978 the Coast Guard responded to 78,000 calls for assistance. Ninety-four point two (94.2) percent of the units assisted were vessels. Four and one-half (4.5) percent were persons only. Seventy-eight point two (78.2) percent of the vessels were used for recreational purposes. Eleven point nine (11.9) percent were commercial fishing vessels. Less than 2% were merchant ships. Figure 6 gives the distribution of length of assisted vessels. About 67% of the vessels were disabled, about 15% had run aground, 5% had capsized and about 6% were overdue/missing. In other words, the overwhelming majority of SAR missions are to aid small to moderate size recreational boats which are afloat or grounded and immobilized. Eighty-one percent of the incidents are within three miles of the coastline and 95% are within 25 miles.

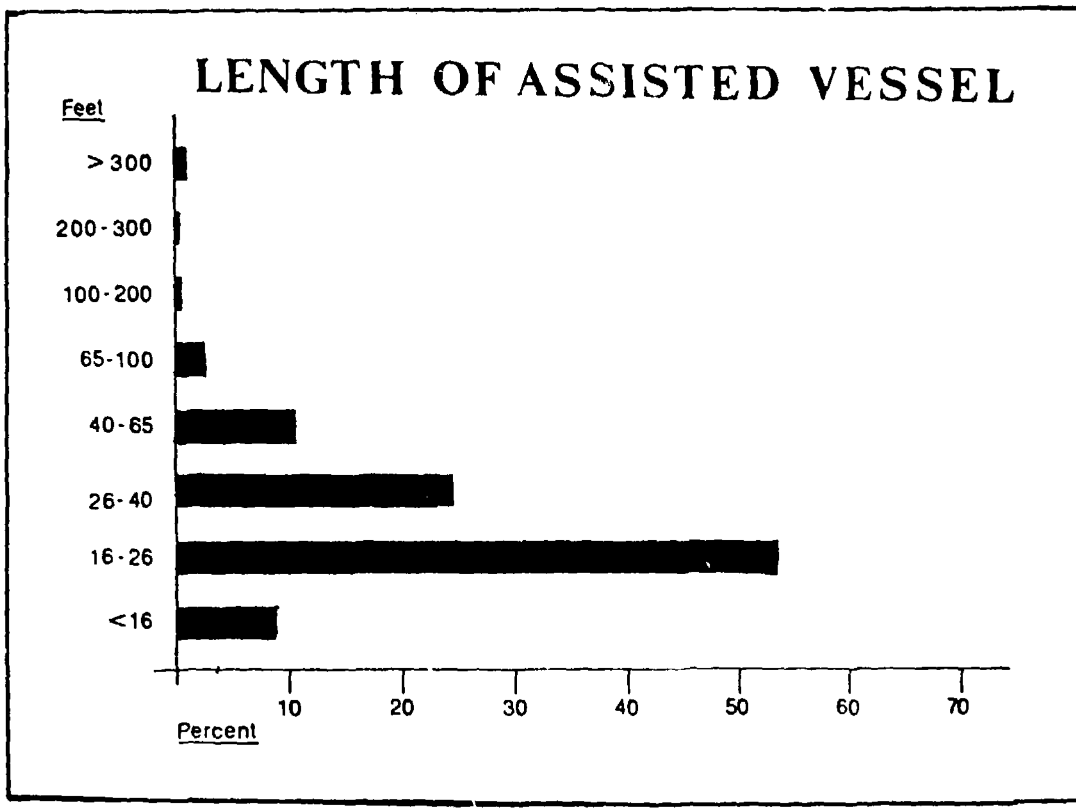

Figure 6. Length of Assisted Vessels.

3.7.2 Search Operations

Searching is involved in 13% of the cases but consumes 22% (over 48,000 hours) of the total sortie hours. The distressed unit is found in about 41% of the search cases. Of the nearly 228,000 total annual sortie hours, boats account for 58%, cutters 15%, the auxilliary 10%, and aircraft 10%. Indirectly, all of these figures indicate that a lot of the search time is put in by vessels as well as aircraft. However, projections indicate greater use of aircraft in the future.

The SAR statistics must be interpreted with caution. For example, some of the reported boat search time may be travel time to and around the area that aircraft are searching and not truly be independent searching by the boat. Furthermore, reports customarily lead to a search for the boat which is missing. However, the boat may have sunk, and at some point, the search becomes one for people in the water. In fact, the people may already be in the water while the searchers are still oriented towards finding a boat. Obviously finding people in the water is more difficult than finding a boat. Next year, boats will be required to carry orange panels and flares to facilitate detection and identification of those in distress.

The personnel interviewed indicated that calls for assistance generally originate from three sources:

- A call from the distressed unit
- A call from another vessel alongside the distressed unit
- Notification from friends or relatives that a party is overdue.

There are instances of hoaxes. Some of these are thought to be aimed at diverting Coast Guard resources from drug interdiction missions. Also, vessels which have called for assistance sometimes fix the problem themselves or get other help and fail to notify the Coast Guard.

Almost all searches originate with the third source. However, occasionally a distressed party which calls for aid will not know exactly where it is. Most searching is done during the day. The Coast Guard does

have fixed wing aircraft equipped with the "Carolina moon" which can illuminate a one-half mile square area from an altitude of 500 feet. In some cases, Air Force resources are called on to make high altitude photographic searches. Then a large amount of film must be reviewed to determine if the distressed vessel was overflown.

3.7.3 Underwater Search

Currently the Coast Guard does not have an underwater SAR capability. As submersibles are used more for offshore commercial activities and recreational purposes, the Coast Guard may be called upon to provide SAR services. Personnel could become stranded in malfunctioning or entangled submersibles and have a good chance of surviving if their vehicle is retrieved quickly. There is also the possibility that people may be stranded in parks or other underwater recreational facilities. Although scuba diving will increase in popularity and divers will be able to go to greater depths, it is doubtful that an underwater SAR capability will contribute much to the survival chances of a diver in trouble.

3.7.4 Conclusions

The forecasts project a strong rate of growth of recreational boating (see Section 2.4.3). The SAR workload has been highly correlated with recreational boating activity. However, in the future, the Coast Guard may attempt to reduce its involvement in search and rescue operations. Efforts will be made to have state and local agencies and the auxiliary respond to most assistance calls. A marine organization similar to the automobile club also might come into being. The Coast Guard would emphasize its role of establishing safety equipment requirements and standards.

It is difficult to anticipate how animals might be useful aiding a distressed vessel once a Coast Guard unit arrives on the scene. However, animal sensory capabilities may be used to increase the effectiveness and reduce the time and costliness of search operations. An animal search

system should be optimized for locating small vessels (between 12 and 65 feet in length) or people in the water in a variety of sea states and weather conditions. Although many boats being sought would be disabled, that probably is not a good discriminating characteristic, i.e., some overdue boats may be quite functional. A nighttime search capability will be useful. A system is needed for operation from fixed wing (including jet) aircraft and helicopters. Also, a system which could give longer range eyes to Coast Guard boats would be valuable. Since so many incidents are within a few miles of shore, a land based animal search system could be considered.

An animal system for underwater search for submersibles and for recovery of those vehicles may also be valuable in the future.

3.8 ENVIRONMENTAL PROTECTION[10]

Detection, tracking, control, and investigation of oil leaks, accidental spills, and intentional dumping have been and will continue to be the Coast Guard's main involvement in environmental protection. Major incidents such as oil well head blowouts and tanker collisions or breakups are reported to the Coast Guard. The Coast Guard and the commercial interests involved in such incidents have containment booms, dispersement, and skimming/vacuuming equipment to help control and minimize environmental damage from those accidents. Other incidents where there is visible evidence of pollution such as films on waterways or fish kills may be reported to the Coast Guard by observers of the evidence.

The Coast Guard does conduct multi-purpose surveillance flights (pollution detection and law enforcement). During these flights intentional pumping of bilges or bunkers of ships may be detected. A surveillance system has been contracted to go on the new intermediate range jet aircraft. This system has infrared detectors, cameras, and a side scan radar. The surface film left by a ship dumping oil contaminated fluids can be tracked back to the ship. One problem is that flights are now and will probably continue to be too sporadic to detect most violators. The extent and move-

ment of oil on the water surface also can be charted by aircraft. However, the depth of the layer cannot be determined. When the oil washes ashore, it is difficult to determine how far it has penetrated into such inaccessible and ecologically sensitive areas as mangrove swamps.

With regard to oil rigs, to date the Coast Guard has only had responsibility for inspection of equipment and procedures related to personnel safety. In the future it is anticipated that those inspections may be extended to cover environmental protection control devices.

As shipping of hazardous chemicals increases as projected, the Coast Guard will become even more concerned than it is now with detection, plotting the extent of, and controlling the effects of chemical accidents. Spills into rivers, streams, and sewers are of concern as well as offshore events. Detecting many of those chemicals when dissolved in water can be difficult. Currently, water samples are taken to private laboratories and the tests performed are expensive. Complex laboratory testing also may be involved in identifying the source of hazardous chemicals or oil so that control measures and legal action can be taken.

3.9 MILITARY OPERATIONS

Coast Guard involvement in military operations of the United States will be dependent upon the nature and location of the conflict. Some of the missions which the Coast Guard will be asked to perform are natural extensions of current and projected peacetime missions, but they may be conducted on a larger scale. In a widespread conflict some may even be carried out in U.S. waters. Other missions, discussed below, are considered because they will be conducted in the natural and operational environments in which the Coast Guard is accustomed to working, e.g., coastal waters, port approaches, harbors and inland waterways.

3.9.1 Combat Search and Rescue

During warfare the Coast Gurad search and rescue resources can be augmented, and utilized to rescue survivors of:

- Ships sunk in sea lanes or U.S. coastal waters.
- Ships or landing craft sunk in the course of amphibious operations.
- Naval vessels sunk in surface engagements.
- Aircraft downed in naval engagements or while conducting airstrikes in coastal areas.

In World War II the Coast Guard rescued thousands of survivors of torpedoed ships along the Atlantic and Gulf Coasts, in the Caribbean, Atlantic, and Mediterranean. Over 1,500 survivors of landing craft sunk by German guns were picked up during the Normandy landings.[11]

There were significant losses of personnel following World War II naval engagements in the Pacific when men were left in the water for several days. It has been suggested that in the future Coast Guard cutters and helicopters operating with task units could be used to rescue survivors from ships sunk in battle. Combat vessels may not be able to stop, search for, and rescue personnel.[11]

3.9.2 Defense Against Swimmer Attacks

During wartime there may be a threat of attack by swimmers to U.S. Navy combat and supply ships, merchant vessels, and POL and munitions facilities along the shore. Such a threat materialized during the conflict in Vietnam. If the Coast Guard develops the peacetime capability to protect ships in port from terrorist attacks, that capability would find direct application in wartime. The Coast Guard would likely be responsible for port security in the United States. A good system for defense against swimmer attack would find even more utility in foreign ports protection U.S. ships and those of our allies being supplied.

3.9.3 Protection of Offshore Assets

The Coast Guard will not have the resources to protect U.S. offshore assets from attack by any substantial naval force. However, it could be

given the responsibility for security of selected facilities against small unit attacks. Protection from commando-type raids or swimmer attacks might be provided. Like the mission of protecting ships in port this would be an extension of the projected peacetime mission of terrorism control. Coast Guard surveillance of areas with high levels of offshore activity could be expected to increase.

3.9.4 Mine Countermeasures

The Coast Guard does not have the sensor or neutralization systems to sweep or hunt mines. However, this mission is often conducted in coastal waterways, the environment in which the Coast Guard is best prepared to operate. It would be valuable if the Coast Guard had the capability to determine if a port or port approach had been covertly mined and be able to nullify that threat. Such a capability would be particularly valuable if the Navy's limited mine countermeasures resources are required to cope with other mining threats overseas.

3.9.5 Natural Disaster and Domestic Emergency Operations

This mission is listed under military operations although it is just as likely to occur in time of peace. The use of military forces and military type logistics operations are typically required to provide aid during natural disaster.

The incidence of natural disasters along the U.S. Coast should not be any greater in the next twenty-five years than they have been in the past. However, with increased population and more industrial development near the shore, the consequences could be more severe. The processing, storage, and transportation of more explosive and toxic materials near population centers also poses an increased threat.

The newly formed Federal Emergency Management Agency among its other responsibilities, coordinates and plans for emergency deployment of resources responding to disaster situations.

Of course, Coast Guard personnel and vehicles can contribute to the logistics aspect of relief operations. Another task which the Coast Guard might be asked to perform is to find and rescue survivors. Although this is related to the Coast Guard's regular search and rescue activities, there are distinct differences. The people being sought are not likely to be on expanses of open water. They may be on top of flooded buildings or among debris on land. Many may be injured. There may be a need for body searchers.

3.10 REFERENCES

1. "Facts and Forecasts." Ocean Industry, October 1979, p. 66.

2. "Trends in Offshore Drilling." Ocean Industry, January 1979, pp. 35-46.

3. "1979 Tabulation of Subsea Completions." Ocean Industry, July 1979, pp. 46-53.

4. "Facts and Forecasts." Ocean Industry, October 1979, p. 72.

5. API Bulletin 1500-11 op.cit.

6. Personal communication with A. Robert Matt, Commander USCG (G-015/74), Washington, D.C.

7. Many of the ideas expressed in Section 4.6 resulted from discussions with Commander Larry R. Hyde, Chief, General Law Enforcement Branch, Coast Guard Headquarters, Washington, D.C.; Commander George Martin, 7th District Headquarters; Lcdr. Tulich, 11th District Headquarters, and Lcdr. Robert Council, 12th District Headquarters.

8. Commandant Instruction M16107.1 (old CG-489), Subject: SAR Statistics - 1978, 13 March 1979.

9. Lcdr. John Carroll, Coast Guard Headquarters, Lt. Gerald Bowersox, 7th District, Lt. Bill Bradford, 11th District, Lcdr. Robert Council, 12th District.

10. Discussions with Lt. J. G. Habib, Coast Guard 11th District Headquarters, Lcdr. Robert Council, 12th District Headquarters, and Cdr. William Wilkins, 7th District Headquarters.

11. Larzelere, A. R., Capt. U.S. Coast Guard, Future Wars and the U.S. Coast Guard, Proceedings/Naval Review, 1979.

4.0 SUMMARIZED REVIEW OF ANIMAL CAPABILITIES

4.1 INTRODUCTION

4.1.1 The Problem

The number of unique and unusual animal capabilities and senses is nearly as great as the number of individual species. That is, each of the millions of animal species represents a unique biological entity with its own way of perceiving and dealing with the environment. Furthermore, a species cannot be dealt with as an isolated capability, but is an individual biological entity with a unique pattern of characteristics. Both the huge variety of capabilities and the individual unique qualities of each organism are important problems to be overcome in this review, since each is an important consideration in system concept formulation. These problems are further complicated by the fragmentary and nonsystematic way in which sensory physiology data is currently accumulating. Most sensory information is in a primitive state, being non standardized, often contradictory and dispersed erratically throughout the scientific literature.

In order to deal with the above mentioned problems an approach was developed for conducting the review of animal capabilities which provided a systematic and reasonably comprehensive review within finite time and space.

4.1.2 The Approach

Figure 7 shows schematically the approach taken for reviewing animal capabilities. This approach will be described briefly below.

Initially, potentially useful sensory modalities and capabilities were listed within the broad context of current and future Coast Guard missions (Box 1). Concurrently, a list of animals was compiled from the entire animal kingdom, eliminating only a few animal groups which were unquestionably impractical for Coast Guard use (Box 2). Criteria for elimination included size, maintenance, legal, economic and biological considerations. The capability and animal lists were then matrixed and a list of potentially useful animal-capability areas resulted, (Box 3).

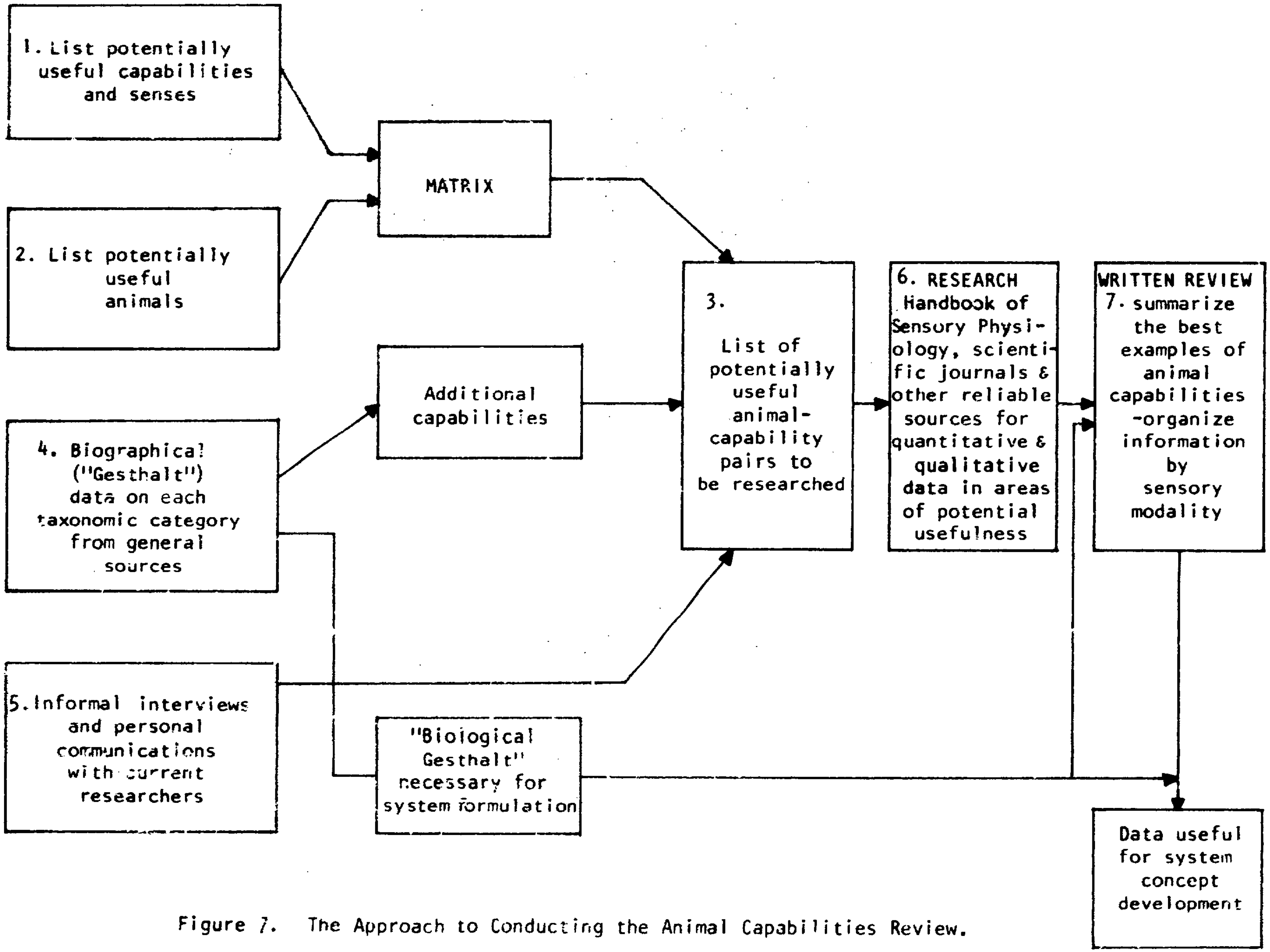

Figure 7. The Approach to Conducting the Animal Capabilities Review.

Box 4 represents a general review of the entire biology of each animal group which resulted in a "biological portrait" of each group. This information was useful in two ways. First, additional areas of potentially useful capabilities were discovered and added to the list of capabilities to be researched. Secondly, the biological portraits obtained provided the aforementioned Gestalt information for each animal group necessary for realistic system concept formulation. Informal interviews and personal communications with current researchers also added to the list of potentially useful animal capabilities. The majority of research time (represented in Box 6) was spent accumulating quantative and qualitative data on the listed animal-capability areas. A variety of scientific books and journals, The Handbook of Sensory Physiology, and other reliable sources were utilized. The information obtained from research was then organized by modality or capability and is presented in the tables and text of this review. In the interests of clarity, utility and space the review text has been selectively edited such that only animal capabilities with at least remote potential for system applicability are described.

4.1.3 Preface to the Capabilities Review

The scientific methods for obtaining animal capability information start with simply watching animal behaviors. Anatomy and physiology are subsequently studied to support the existence and sensitivity of a particular capability. However, many parameters of sensory capacities are difficult to assess and therefore, most data is now being produced by two other methods of research, namely training experiments and electrophysiology. Crudely stated, training produces animals that respond in some way to a stimulus and then that stimulus can be altered until the response is no longer observed thus revealing a behavioral threshold for that stimulus. In a similar crude way, electrophysiology consists of giving stimuli to a receptor organ then recording and analyzing the electrical activity in the nerves from that organ. The many variants and modifications to these basic techniques have provided most of the information that follows.

This review is not, nor could it be, completely comprehensive because the subject of animal capabilities is enormous and many such capabilities are

unknown or incompletely tested. Thus it is possible that the "perfect animal" for a particular system application exists, but may not be mentioned specifically in the review. However, the review does present outstanding animal examples of all relevant capabilities from all relevant animal groups, and these examples can serve as indicators of the best the animal kingdom has to offer. It is important to be aware that there are many unmentioned organisms that, by virtue of their phylogenetic and ecological similarity to the examples given, have similar (but usually lesser) capabilities.

Often the sensory capability of an animal will be mentioned even though the sensory capacity in question is quite poor relative to other animals. This is frequently done because the potential usefulness of some organisms lies not in a single outstanding capability, but in a combination of lesser abilities, i.e., in the Gestalt qualities of the biological whole.

A brief qualitative summary of the review of animal capabilities will be given below. For additional details, references and quantification of these capabiliti s, the reader is referred to the tables, text and references in Appendix A.

4.2 VISUAL CAPABILITIES IN SELECTED ANIMAL GROUPS

Some type of light sensitivity exists in every animal phylum, but the most relevant examples of vision are the cephalopod mollusks (e.g., octopus), fish, sharks, seals and sea lions, and, above all, birds.

Octopus vision can be characterized by several advantages and several disadvantages with respect to human vision. The octopus has poor size and color discrimination, has no binocular vision and is also poor at pattern discrimination. However, the octopus can discern the plane of polarized light, adapt to very low light intensities, and sees with an acuity of 17 min. of arc (the best of all invertebrates). In addition, octopus vision covers a very wide field of view.

Sharks are potentially quite useful animals. They possess excellent visual sensitivity to movement and contrast, and have extremely rapid and complete adaptation to low light intensities, allowing them to see in light ten times lower than man's lowest threshold. The field of view is very wide, but sharks have poor visual acuity and little or no color vision.

Some photic zone fishes have color vision and acuity comparable to man. A wide field of view and binocular vision are competitive goals which are variably expressed in these fishes. Deep sea fishes in contrast have generally poor acuity and color resolution, the field of view is usually limited, and binocular vision is often present. These limitations in deep sea fish are adaptations to allow sensitivity to extremely low light.

Birds possess the most advanced vision in the animal kingdon. The fovea is a retinal area usually associated with high visual acuity and good color vision. This area is large and highly adapted in many birds. Diurnal birds generally have a fovea, high acuity, and good color vision. Hawks, eagles, and vultures are the best examples of good acuity (e.g., Buteo buteo a vulture has acuity eight times that of man). Movement sensitivity and contrast detection are also excellent in most diurnal birds. Owls have relatively poor color discrimination and are red blind, but possess low intensity vision 100 times better than man. Pigeons are noteworthy for excellent movement sensitivity and the detection of ultra violet light as well as the plane of polarized light. The avian field of view is typically wide,and binocular vision is usually present. In addition, accomodation is very rapid in most birds; in some it is so strong that they can see well both in and out of water (e.g., cormorants). Many birds are readily trainable for performance of visually oriented tasks.

Seals and sea lions (Pinnipedia) have good (4-6 min. of arc.) visual acuity both in and out of water. They can also see well in low light intensities. Furthermore, they are highly trainable for underwater tasks. Pinnipeds can discriminate small differences in size and shape and have binocular vision but have almost no color vision.

4.3 THERMORECEPTION IN SELECTED ANIMAL GROUPS

Thermoreception is limited to a relatively small number of animals and is only well developed in a few fish, insects, and reptiles. The thermosensitivity of the best endowed animals (pit vipers) is easily matched by man-made thermosensors, and thus the applicability of animal thermosensitivity in a system context is unlikely.

4.4 CHEMORECEPTION IN SELECTED ANIMAL GROUPS

Almost every living organism has some type of chemosensitivity. Among the invertebrates, bacteria, molluscs, and insects have the most useful chemoreception. Among vertebrates, fish and mammals are outstanding. Humans have exceptionally poor chemoreception so it is difficult to imagine that odors form the primary means of communication in many, and possibly most, animal species.

4.4.1 Bacteria

Bacteria have part per million range sensitivity to some compounds but show low specificity of response. They could be quite useful because of low cost, expendability, and their potential for genetic selection. If sensitivity to appropriate chemicals and observable responses can be developed, bacteria will make excellent chemosensors.

4.4.2 Insects

Insects have the same advantages and disadvantages as bacteria. They are highly sensitive but response to important chemicals and a response indicator must be found. Insects have a variety of chemoreceptors including the four "tastes" that humans possess as well as many specific receptors for particular chemical classes (e.g., alcohols, CO_2, ketones, etc.). A good example of system use of insect chemoreception is the utilization of the isolated honeybee abdomen for detecting pollutants, certifying water purity, and detecting drug administrations. Some insects have incredible sensitivity

and specificity for biologically important compounds called pheromones. The behavioral response to a pheromone is usually stereotyped and reliable, thus it is easy to observe when a detection has occurred. Some sex attractant pheromones have been analyzed and synthesized for use in insect control programs. Pheromones are among the most powerful chemical stimuli known and therefore are potentially useful in their unmodified form.

4.4.3 Marine Animals

A variety of potentially useful marine animal chemosensitivities will be mentioned below. The octopus has contact chemoreceptors in its suckers that respond to sweet, sour, and bitter stimuli with 100 times the sensitivity of the human tongue. Sharks and rays have highly sensitive (part per billion range) and directional olfaction, especially when the stimulus is a food related odor. The common chemical sense is also well developed in sharks. Some fish are sensitive to the four "tastes" and a variety of other chemicals at concentrations thousands of times lower than man can detect. Also, some species can be imprinted on dilute chemicals during an early critical period of life and will maintain a response to that chemical through maturity. The chemical sensitivity of some fish has allowed their use as pollution indicators as sensitive as the best analytic techniques. Finally, certain eels show the greatest chemical sensitivity measured in any animal group, but the capability is severely limited.

4.4.4 Birds

Procellariform birds (e.g., Northern Fulmar) have good olfaction. Other potentially useful candidates are Oil birds, Grebes, Honeyguides, and the Turkey Vulture. Homing pigeons also may use olfaction in orientation to the home loft. These olfactory abilities combined with the ability of flight may be useful.

4.4.5 Mammals

Olfaction is highly developed in most mammals higher on the phylogenetic tree than rodents. Pigs have phenomenal olfaction as do dogs, with sensitivity

in the part per billion range for many stimuli. In addition, dogs are highly versatile, easily trained and have been demonstrated as excellent animals for systems applications. Some system applications and preferable breeds of dogs are detailed in Sections 5 and 6 and Appendix A.

4.5 AUDITORY CAPABILITIES IN SELECTED ANIMAL GROUPS

The auditory capabilities of birds and several mammals may be important in system applications.

4.5.1 Birds

The high frequency range of bird audition is typically limited relative to man. However, pitch discrimination is similar to man and temporal resolution is usually better. For example, pigeons are limited in high frequency hearing to only 12 KHz. Their pitch discrimination is unusually poor for a bird, but pigeon temporal resolution is better than man. The maximum sensitivity range of pigeon audition is from 1800-2400 Hz. and they are unusally sensitive to infrasonic vibrations. Owls are exceptional birds with respect to auditory functions. For example, Barn Owls have extremely accurate three-dimensional auditory localization facilitated by many adaptations including extremely sensitive high frequency hearing.

4.5.2 Mammals

Many mammals are sensitive to sound frequencies that are beyond human perception. However, threshold intensities are rarely significantly better than man.

Rodent audition is characterized by a broad frequency range (0.1 to 100 KHz) and threshold sensitivity slightly higher than man at our frequency of maximum sensitivity.

Bats have an even broader frequency range (1-150 KHz) than rodents. Bat temporal resolution is extremely fast and sensitivity thresholds are low, these capabilities being related to echolocation.

The frequency range of dogs extends over 25 KHz and that of cats goes over 60 KHz. Threshold sensitivity of dogs is comparable to man while cats are a rare exception, having significantly lower absolute sensitivity thresholds over a broad range of frequencies.

The toothed whales have excellent audition with a broad frequency range (typically 0.07 to 150 KHz) and thresholds almost as good as man in our optimal range and much better in the high frequencies. Odontocetes (toothed whales) also have rapid temporal resolution which, as in bats, is related to echolocation.

4.6 ECHOLOCATION IN SELECTED ANIMAL GROUPS

Echolocation is utilized by bats, toothed whales, a few birds and shrews, a fish, and possibly rodents and seals. The most relevant of these animals to Coast Guard missions are the toothed whales (Odontoceti).

Toothed whales produce a species specific, high frequency, directional beam of rapidly pulsed sound which is reflected off underwater objects and then received by audition characterized by high sensitivity and rapid temporal resolution over a broad frequency range. This process allows the determination of the presence, location, size, shape, and composition of underwater objects. Blindfolded dolphins can swim mazes and avoid thin (.35 mm) wires without contact. They can resolve thicknesses of different targets and also can distinguish between similarly shaped objects. Echolocation range is on the order of 50-100 meters and may operate over 300 meters on large targets. Range can be limited by acoustic reverberation and noise. Size and shape resolutions generally have threshold levels from 5% to 10% at short range, and most of a variety of materials thus far tested can be differentiated by the Atlantic bottlenose dolphin (Tursiops truncatus) utilizing only echolocation. Finally, range resolution is also well developed, i.e., Tursiops truncatus can detect a difference in distance to two objects even if the distance difference is under 1% (only

tested up to 7 meters). Finally, proven echolocation exists in nine species of odontocetes, of which seven are amenable to captivity and training.

Bats are also accurate echolocators and can determine the presence, size, shape, direction, distance, velocity, and nature of airborne objects. However, bats and a variety of other echolocators have no obvious utility for the Coast Guard. They are discussed briefly in Appendix A.

4.7 TACTILE SENSITIVITY IN SELECTED ANIMAL GROUPS

Tactile senses are potentially important as accessory senses to other tasks animals may be required to perform. Many invertebrates (e.g., protozoans, flatworms, anemones, crustaceans and insects) show behavioral responses to minute tactile stimuli, however such tactile sensitivities have not yet been quantified. Vertebrates, especially humans, cats, rodents and primates have been more thoroughly studied. Most mammals appear to have tactile sensitivities which are generally very similar to man, however, unique tactile sensitivities exist in every class of vertebrates (e.g., substrate vibration sensitivity in snakes and salamanders).

Generally speaking, there are two categories of tactile sensitivity in vertebrates. The first category includes internal tactile senses which monitor body position and movement and the status of internal organs. The second category of tactile sensitivity is cutaneous reception, including mechanoreceptors and pain receptors. Mechanoreceptors in hairless skin are what we consider to be the "sense of touch" while mechanoreceptors in hairy skin (e.g., vibrassae) afford some mammals with an extended receptive field. Pain receptors appear anatomically similar in all vertebrate classes except Elasmobranchii (i.e., sharks), but the perception of "pain" per se can only be assumed on the basis of behavioral responses which are similar in almost all vertebrates.

4.8 ELECTRORECEPTION AND MAGNETIC FIELD SENSITIVITY IN SELECTED ANIMAL GROUPS

Electroreception and magnetic field sensitivity are present in a surprisingly wide variety of organisms from bacteria to birds. Electroreception can be divided into two categories, active and passive. Active electroreception occurs in two families of fresh water fish and is characterized by the animal producing and receiving its own electric field, thus detecting nearby objects and organisms via distortions in the field. Passive electroreception involves detection of electric fields produced by external sources. Passive electroreception is present in a wide variety of organisms, but is most highly developed in the sharks and rays.

Magnetic field sensitivity can be achieved via electromagnetic transduction, direct magnetic sensitivity, or other unresolved mechanisms (see Appendix A). Bacteria, insects, and snails utilize direct magnetic sensitivity, electromagnetic transduction is utilized by elasmobranchs, and the unknown mechanisms of magnetic sensitivity probably operate in the homing pigeon and green sea turtle.

Sharks are potentially quite useful for a variety of reasons, among them being a phenomenal electrical sense. Elasmobranchs can detect slowly oscillating electric fields of as little as 0.01 μv/cm. This ability is normally utilized for prey capture within 1 meter via prey produced bioelectric fields. Such sensitive electroreception also allows detectable electrical transductions by a variety of other useful stimuli such as current boundaries, thermoclines, salinity or chemical differences in the water, and the earth's magnetic field. Electrically mediated magnetosensitivity provides a shark with compass direction as well as information about its own velocity and direction of movement. Sharks may also be aware of their latitude on the globe by analysis of magnetic stimuli.

4.9 MISCELLANEOUS CAPABILITIES AND CHARACTERISTICS

A variety of miscellaneous capabilities and characteristics that can't be classified into specific sensory modalities are mentioned in Appendix A, and thresholds, if known, are given. These abilities may possibly prove useful in certain system contexts. The capabilities and characteristics worthy of consideration are listed below:

- Diving abilities, especially in dolphins, whales, seals, and a few birds
- Load carrying abilities
- Territorial behaviors
- Hibernation
- Imprinting (a type of learning)
- Drug and hormonal behavioral responses
- The potential use of genetic alternations

Migrations, although amazing in length and extensively documented in a large number of animals, have no apparent utility for the Coast Guard and are therefore not discussed.

5.0 HISTORICAL PERSPECTIVE ON USES OF ANIMALS

5.1 INTRODUCTION

5.1.1 Purpose

This historical overview of past animal uses along with the following summary of current developments provides a valuable perspective for considering future uses of animals. An understanding of the commonalities of successful developments and the problems which led to system failure or disuse will provide a basis for formulation of system concepts which are useful, realistic, and durable.

Biosystems have typically had histories of need, therefore, development and use, followed by disuse and loss of information. Most system developments have been poorly documented and therefore, subsequent developments have not had the benefit of an historical data base. This perspective will provide such a data base and thereby prevent duplicated efforts.

This review is bibliographical in nature to facilitate research into past systems and make available the information that does exist on their development and use. Citings come from a variety of scientific, military, and historical sources. A comprehensive treatment of the use of animals for warfare and crime control is in Lubow's book, The War Animals.[1]

5.1.2 Organization

It is convenient to view animal systems as having developed in three stages, paralleling gross cultural changes. Accordingly, the review will be organized in a chronological order, and animal uses will be reviewed in a framework consisting of a hierarchy of three increasingly complex cultures. Each culture created certain needs, and therefore, animal uses fulfilling those needs. The three cultural divisions are: hunting and gathering, farming and trading, and technical-industrial.

After reading the review of animal uses it will become apparent that there is a trend toward increasingly elegant training procedures in order to modify and utilize the complex behavior of higher animals. A basic understanding of training principles and procedures is essential for evaluating the feasibility and effort involved in developing a trained animal system. Accordingly, a brief description of training principles is outlined, followed by three examples (dolphin, pigeon, dog) illustrating, via training procedures, the underlying principles.

5.2 ANIMAL USES IN HUNTING AND GATHERING CULTURES

These cultures were the first formed and were concerned primarily with obtaining food and shelter. Animal uses were correspondingly simple, paralleling simple cultural needs. Obviously, animals were a source of food, but secondary animal products were also valuable, for example: pelts, wool, leather, and ivory. Observation of the natural behavior of animals aided man. Particular flockings of birds were (and still are) used to deduce the location of fish, and cyclic behavioral changes (e.g., migration) helped indicate the chan g of seasons. Another example of utilization of natural behavior was the use of tethered cormorants to capture fish. Domestic dogs evolved with man, each simbiotically providing special skills in order to more successfully hunt, track and kill other animals.

5.3 ANIMAL USES IN FARMING AND TRADING CULTURES

These cultures were (and are) larger and more complex than the primeval hunting and gathering types. With the advent of farming and trading, communication became important and armed conflict increased in size and organization. In addition, increasing leisure time created a need for intellectual fulfillment. Each need in the culture was partially satisfied by the use of animals.

5.3.1 Farming

Animals were captured, domesticated, and eventually selectively bred to supply needs for food and secondary animal products. The ever pre

increasingly domestic dog was trained to guard property and herd other domestic animals, while larger beasts pulled plows, towed wagons, or turned wheels for irrigation or grinding grain.

5.3.2 Trade and War

Many animals were captured and trained to transport loads for trade or warfare. Beasts of burden varied according to what was available in the locality. The biggest docile herbivore available was generally used, for example: camels, llama, oxen, elephants, donkeys and horses. Wartime uses of animals became significant, Hannibal's elephants being a familiar example. Two other less known wartime uses of animals are interesting. A biblical example (Judges 15:4-5) is that of Samson capturing foxes, igniting their tails, and setting them loose to run through the enemies' fields, thereby burning the crops. Also, geese were used as guards in ancient Rome to cackle when intruders invaded.[2]

5.3.3 Communication

The earliest use of pigeons for communication dates to 4500 B.C. in Egypt and Iraq.[3] Pigeons were used to send messages in the Roman Empire. Hundreds of years later, the defeat of Napoleon at the Battle of Waterloo[4] was communicated by pigeons. Use of the pigeon for carrying messages depends on the pigeon's ability to return to its home cage after being carried many miles away. In other words, the system was limited to carrying messages unidirectionally, and to a fixed location.

5.3.4 Companionship and Entertainment

Increased leisure time created novel uses for animals. Other abstract uses of animals helped satisfy the need for entertainment. Examples include butterfly collecting, pets, horse and dog racing, toad jumping, and cockfighting. Falconry was the leisure activity of kings. Many old entertainment uses have remained through the present and many others have arisen.

5.3.5 Symbols

Many animals were utilized as mascots or symbols. Representative examples are the use of birds as: symbols of dieties (the Christian holy spirit is a dove), symbols of wisdom (the owl), symbols of power (the condor or eagle), and symbols of war and peace (the hawk and dove). The examples of animal symbolism were widespread, varied, and have remained extremely useful to the present (Smokey the Bear, sacred cows, and a partridge in a pear tree).

5.4 ANIMAL USES IN TECHNICAL-INDUSTRIAL CULTURES

All of the aforementioned animals are still utilized in modern industrial nations, some for the same basic purposes, but others, having been replaced by mechanization, are being utilized in new ways, reflecting new needs. For example, the horse was used for basic trade and transportation, but having been largely replaced by functionally superior machinery, is now being used more for leisure activities such as horseback riding, rodeo, racing, polo, fox hunts, etc. Now different species also are being employed in increasingly complex ways as our scientific knowledge allows their exploitation. Examples will follow.

5.4.1 Recreation and Entertainment

Recreation and entertainment are vital to industrialized cultures inasmuch as they allow escape from feelings of alienation and helplessness, which can become severe problems in this type of culture. A mention of the massive use of animals in this regard is important. Leisure employment of animals is so commonplace we tend to forget its magnitude. Many animals previously used for basic needs now provide fulfillment of our equally important personal and leisurely desires. The horse is a good example. Other examples include the use of would-be draft animals in hayrides, circuses, and zoos; and the incredible number of pets we own, reflecting both our increased need for companionship and our increased ability to pay for it.

Hunting and fishing, once a necessity, have become sports. Modern zoos and aquaria; animal shows; horse, pigeon, greyhound, and turtle racing; frog jumping, tropical fish; your dog or cat; Bugs Bunny and Mickey Mouse; all fill read contemporary needs.

The recreational and entertainment uses of animals are relevant to this project. Such uses have contributed a great deal of the knowledge on behavior of those animals in captivity, their training, care, and breeding.

5.4.2 Symbolic Uses

Symbolic uses of animals were mentioned in the context of farming and trading culture. Animal symbolism is still very important, and touches almost every aspect of technical-industrial culture. Religions, political parties, nations, professional sports teams, in fact, most large modern entities have animal symbols. This is also especially true of commercial products; animal use in advertising is astounding. No more will be said of symbolic uses except that employment of animal symbols is widespread and effective.

5.4.3 Medical and Scientific Uses

Animal use in these fields is massive and spans all phylogenetic lines, from bacterial synthesis of antibiotics and vitamins to the employment of higher primates in testing the new and dangerous technologies of space, the deep sea, and potentially toxic drugs and chemicals. Examples are too numerous to mention or even classify. Bionics (a new field concerned with utilizing animal capability and structure as a source of engineering ideas) is a noteworthy area of modern animal use.

5.4.4 Organism Control

With increasing ecological knowledge, it is becoming possible to control the spread of organisms which are creating problems for man with other organisms of the same or different species. An example is the successful introduction of

Chrysolina quadrigemina (beetle) into Northern California to combat the epidemic spread of Klamath weed (Hypericum perforatum). Another example was the successful introduction of Cactoblastis moths to eat prickly pear cactus flowers and thereby stop epidemic prickly pear infestation in Australia.[5] Sometimes such uses can, in the long run, have adverse consequences. The organism introduced as the control measure can multiply rapidly and start consuming desirable plants or animals. This undesirable situation has occurred several times as a result of accidental or intentional animal introductions, examples of which will follow. The mongoose was introduced to Hawaii to control rodent infestation (also introduced) but the scheme failed and the mongoose population survived by eating the eggs of endemic birds, thereby endangering several species. The introduction of many placental mammals to Australia has led to extinction of endemic marsupial forms. A final Hawaiian example is the introduction of nonendemic birds which, by a combination of factors including disease and competition, have caused widespread extinctions of native birds.[6] This potential danger is always present because of our lack of thorough understanding of complex ecological interactions.

A variety of animal mechanisms for controlling the spread of insects are known. An example is raising quantities of males, sterilizing them, and then releasing them in an infested area. This controls the population growth. Also, by use of synthetic pheromones, males can be attracted to a location and poisoned. Predatory insects and birds have also been used with more limited success.

5.4.5 Use of Untrained Animals as Sensors

With recent advances in electronic sensors, our awareness of the unique sensory capabilities of animals decreased and has only recently been revived. The following are examples of attempts to utilize these sensory capabilities in untrained animals for detection functions.

5.4.5.1 Insects. Insects have been incorporated into several detection systems. The isolated abdominal segments of the honey bee (Apis mellifera) have been used in a pharmacological test system. Many compounds applied at the severed node will induce a unique and recordable series of movements in the abdomen. The characteristic movement can be used to determine the presence of particular chemicals in a sample.[7] Examples of the sensitivity of this system will be given in the appendix.

Much work was done on a human intruder early warning system for a jungle environment. By monitoring ambient jungle noise (primarily insects and birds), "normal" vs. "intruder" noise levels were discernable, but the system was judged not specific enough for operational use.[8]

Another system was devised for trail monitoring using a variety of insects as indicators of a human presence. The insects used were those which quickly detect and respond to humans, e.g., ticks, mosquitoes, bedbugs, and cone nose bugs. Three related systems were organized and tested, but showed only mildly encouraging results.[9-11]

A CIA system, though of dubious validity,[1] at least had a firm theoretical basis. Its purpose was to determine if a selected individual was visiting a certain location. The system involved the use of female cockroach sex pheromone to identify places visited by human individuals covertly marked with the pheromone. Male cockroaches respond vigorously to extremely low concentrations of specific sex attractant molecules (pheromones) produced by female cockroaches. Caged male cockroaches were brought to the location which the selected person was thought to have visited. Their activity confirmed the suspicions that the individual had been at that location.

5.4.5.2 Vultures. Turkey vultures are among the few avians capable of good olfaction, and were used to detect leaks in terrestrial gas lines.

Ethyl mercaptan (an odorous substance in carrion) was pumped into the leaking lines, and aggregations of the wild vultures indicated the location of the leaks.[12,13]

5.4.5.3 Turtles. The snapping turtle, "dog of the American inland lakes," was used to recover a murder victim weighted to the bottom of a turbid lake. Via olfaction, the turtle was able to locate and feed on the body that the police could not find. Recovery involved following a string tied to the turtle's shell to the location of the gruesome feast.[14,15]

5.4.5.4 Killer Whales. Playback of recordings of killer whale sounds is reported to sometimes discourage sea lions and pilot whales from entering an area. The technique has been tested and shows a potential for keeping those animals from competing with fishermen.[16] Finally, a system has been considered for obtaining oceanographic data by using instrumented and radio-tagged cetaceans linked with satellite communication systems.[16]

5.4.5 Bats to Spread Incindiaries

A bizarre WWII system never reached operational status though it showed considerable potential. Incindiary devices with delayed fuses were surgically attached to bats by strings. The idea was to air-drop thousands of bats clustered in bomb-like containers over a target city where the bats would disperse and hide in buildings city-wide, starting thousands of fires.[17] The project was dropped when escaped bats at the Carlsbad Caverns test site started fires that destroyed a general's auto and a two million dollar airplane hangar. Later efforts to revive the project involved putting the bats in hypothermia (hibernation) before the air drop (so they wouldn't chew through the strings) and assuming they would come out of torpor during the long fall toward earth. The assumption was wrong, the bats fell to their deaths, and the project was finally dropped.[1]

5.4.7 Porpoises as Indicators of Tuna Schools

Here is a classic example of how the observations of wild animals can support human endeavors. Yellow fin and skipjack tuna typically run in schools under herds of some species of porpoises (specifically the eastern spinner, spotted , white belly spinner, and common dolphin). Fishermen look for those dolphins on the surface and then surround the herds with huge purse seine nets. The tuna underneath the dolphins are then hauled in. This practice resulted in a great mortality among the porpoises also trapped inside the nets. However, the development of new techniques for getting the porpoises out of the nets without losing the tuna is alleviating that problem.

5.4.8 Trained Animals

Advances in training theory and procedures have allowed innovations in the use of higher animals. Operant conditioning is an important avenue for the communication of information that an animal senses, as well as utilization of a higher animal's capability of performing relatively complicated tasks. Elegant training combined with instrumentation has allowed the synthesis of many operational systems. Most of these systems involved marine mammals, pigeons, and dogs, examples of which will follow. The purpose here is to give examples of trained higher animal capabilities utilized in past systems. Training theory and techniques will be presented later.

5.4.8.1 Marine Mammal Systems. The Navy is currently doing work with marine mammals which, along with other current research, will be considered later. Operational systems previously developed will be reviewed below.

Cetaceans have been trained for release in the open ocean since 1965[18-20] and because of their excellent acoustic sensory capabilities and diving abilities, can frequently accomplish tasks more efficiently and safely than men. Cetaceans have been trained to locate and mark pingered

objects for diver recovery.[21] Such marked objects include mines, depth charges, rocket cradles, and other military ordnance.[16] During the man-in-the-sea program, a 45-day saturation dive at 205 feet, dolphins carried objects between the surface and the fixed bottom location and were trained to carry a safety line to a diver in distress.[16,22]

In Project Deep Ops, killer and pilot whales were trained to locate, mark, and recover pingered cylindrical objects by clamping onto those objects a gas generator which made them buoyant.[23,24] In the course of training, killer whales dove to a maximum of 850 feet while a pilot whale reached 1645 feet. The fastest dive was accomplished by a killer whale that descended 750 feet and returned in 7 minutes 40 seconds.

Project Quick Find is an object recovery system involving attachment of a recovery device to 9KHz pingered objects by the California sea lion (Zalophus californianus). The sixteen month conditioning program produced animals that were capable of retrieving torpedoes and ASROC depth charges at depths of 250 feet, in rough weather, and unfamiliar areas. Sea lions tow a line or cable and clamping device from a small recovery boat to the target object.[19] The system is currently in regular operational use by the Navy to recover weapons undergoing quality assurance tests. It is considered highly successful because of its reliability, the reduction in risks to human divers, and reduced recovery cost.

5.4.8.2 Pigeon Systems. As mentioned earlier, pigeons have been used for communication for thousands of years. Recently, however, some uses have become more complex.

The homing pigeon was used extensively in World War I by both the Germans and the Allies to carry messages from front line units to rear area command posts. The animals succeeded in delivering messages when the devastating gunfire shattered hard wire communications or prevented couriers

from getting through. For example, in the Meuse-Argonne offensive, 442 birds delivered 403 messages safely, the distance varying from 12 to 30 miles. All important messages were delivered. In the battle of Verdun, a pigeon named Cher Ami, though severely wounded, covered a distance of forty kilometers in twenty-five minutes and delivered a message which is credited with saving members of the "Lost Batallion," a unit completely cut off by the enemy.

Also in WWI, British pigeons were air-dropped in baskets over friendly areas where local people banded on useful information which the pigeons then returned to headquarters with a 95% return rate. Another British system utilized pigeon release from downed aircraft in the English Channel to communicate information on the crash site. Seven hundred and seventeen successful reports of downed aircraft locations were communicated in this way. Early in World War II the Germans instrumented homing pigeons with tiny cameras with which they obtained photo reconnaissance on the French Maginot Line.[4]

A World War II application, Project Pelican, was a pigeon-guided missile system that was apparently feasible but never became operational. Pigeons were trained in a simulator to detect and track the picture, projected on a screen, of a target ship. The intent was to carry the birds and use their responses of pecking at the image of the target to guide the missiles.[25]

Pigeons will work for several hours without loss of attention to their task. They have good color vision, and therefore have high potential for simple visual discrimination tasks. Pigeons have been successfully used for quality control discriminations of capsules and diodes. They typically worked at a rate of 1000 selections per hour for four hours straight with very good results.[26]

Ambush Detection Systems were proposed for use in Vietnam based on the pigeons' ability to form "constancy." Constancy is the ability to

recognize an object (a man) as being the same object even though the image on the retina changes in time (man clothed, naked, hiding, lying down, etc.)[27-30] White Charneau Pigeons were trained to recognize men and respond to them in some reportable way. The system involved release of the bird, a controlled reconnaissance flight over the requried area, a report, and return to the release point.[31-34] This system was never fully developed due to cost and lengthy research and the training necessary, especially with regard to controlled flight.[35,36]

Another proposed system utilizing form constancy was to employ pigeons in reviewing masses of U.S. satellite photo reconnaissance to determine "man-made" vs. "non-man-made" objects, thereby eliminating much useless photo reconnaissance data and freeing analysts to work only on photos with man-made objects in them.[27,37,38,39] The system was never fully developed, but constancy was formed in pigeons trained for the idea of "man-made objects," with about 84% correspondence with human observer judgments.

5.4.8.3 Dog Systems. Dogs are friendly and cooperative with their trainers, easily motivated by food and other rewards, and possess excellent olfaction. These and other qualities have allowed the synthesis of many operational dog systems, representative examples of which are described below.

Newfoundland dogs were specially bred and used as shipboard work dogs (e.g., overboard recovery, line carrying between ships, and security) by the British Navy in the last century.

A very old training objective has been the attack dog, the applications of which are obvious (e.g., riot control). Related to this is the employment of dogs in tracking, as has been commonly done with bloodhounds in tracking escaped prisoners and missing persons.[40-42] Systems

have been developed to increase the efficiency of dog tracking,[42,43] many include the use of squalene, a chemical well suited to this purpose.[44,45] Squaline is a chloresterol by-product produced in human skin as a constituent of sweat, but can be found in quantity in shark liver oil. It is odorless to humans, but dogs are extremely sensitive to it even after it has been exposed to weathering for several weeks.[46] Dogs can be trained to track squaline in extremely low concentrations, and by squaline marking border areas or prison clothing, etc., many improved tracking systems have been devised.[47-49] Dogs can also distinguish human odors more readily if the human target differs in diet from other humans in the area. Scenter shoes have also been proposed as aids in tracking.[1] Squaline has also been used to mark the flight recorder in aircraft to allow more efficient recovery.[50] Counter systems to confound dog tracking abilities have been considered, including: drugs mixed with Dimethylsulfate, cocaine, strychnine, tannic acid, obnoxious odors, and odor of female dogs in heat.[51]

Narcotics detection has also been a successful function of trained dogs. Canines have been trained to respond to opium, hashish, marijuana, cocaine, and pure heroin.[51-58] Users have judged the operational system as being very effective.[59-63]

Explosive detection systems have also worked effectively if dogs have been trained to work in the particular environment required.[64,65] Army, Customs Service, RCMP, FBI FAA and LEAA, etc., have all used dogs effectively for explosive detection. Dogs have been demonstrated to be highly sensitive to various explosives, including PETN, RDX, TNT, black powder, ammonia nitrate, potassium chlorate, nitroglycerine, the plastic explosives C-3 and C-4, and ethelyne glycol dinitrate.[66-76]

Operational systems in Vietnam utilized dogs to detect mines, booby traps, pungi pits, tunnels, and tripmines with significant success.[77-83]

The Army conducted a thorough experimental evaluation of its mine detecting dogs in two locales.[82] One simulated a middle European theater of operations during winter and spring. The other corresponded to the Middle East in fall and summer. A variety of practice mines (inert) and distractants were deployed in the test areas as well as several different kinds of live (unfused) mines. Between 67.3 and 85.7 percent of the targets were detected in the spring, summer, and fall tests. During the winter with temperatures aroung 0°C and between 30 and 60 cm of snow on the ground, detection fell to 11%. The study compared the dogs with a metalic mine detector (AN/PSS-11). It concluded that the two were about the same in detection range and search rate, but the dogs were superior in terms of number of types of detectable explosive objects and in false-alarm performance.

Body recovery dogs have been trained and tested [84,85] and others employed[1,86] in an actual operation in the Sinai desert after the Yom Kippur War. The tests and operational use of body recovery dogs show excellent potential for use of dogs in this application, even in varied weather, soil, depth, and age conditions.

Dogs have been trained and tested for ambush detection, area patrol and scouting, and the use of radio controlled brain implanted electrodes has been suggested to provide electronic reward.[87,88,89]

Also, a motion sensitive radio telemetry system (with a personnel alert device) has been devised and tested. The system provides a constant monitor on the dogs' activities and has demonstrated feasibility for personnel reconnaissance.[90] Infrared emitters have been designed and tested for locating patrol and sentry dogs at night.[91]

Finally, in Project Waterdog, a SCUBA swimmer detection system has been devised and tested in which dogs in a patrol boat detect underwater swimmers by odors in their bubbles.[90,93]

5.4.8.4 Other Systems. Stressful individuals sometimes have elevated epinephrine levels in the sweat of their palms. This fact has been utilized in a proposed system in which gerbils are trained to avoid a shock in the presence of elevated epinephrine, and thereby expose stressful persons. This speculative system has been proposed to detect smugglers and hijackers at airports, but no operational systems have resulted.[94] However, it is noteworthy that behavioral evidence does exist that rodents (rats) can detect and respond to an odor in TNT.[94-100]

Seagulls were utilized by the British in WWII as German U-Boat detectors. By frequent release of edible debris from their own submarines, the British conditioned seagulls to follow the dark shadow of a submerged submarine. Thereafter, any aggregation of seagulls not associated with a known British submarine location was investigated.[1]

5.5 TRAINING PRINCIPLES AND PROCEDURES [1,19,83,101,102]

The central problem in developing systems which use trained animals is establishing communications between man and animals. Man must communicate the desired set of behaviors to the animals, and a mechanism must be established for the animals to convey to man the information which their senses obtain. To date, operant conditioning has been the only vehicle available to provide such communication.

5.5.1 Learning Models

Operant (Skinnerian) and Classical (Pavlovian) conditioning are two thoroughly tested learning models employed in animal training. Both contribute to the acquisition of complex behavior, and it is difficult to separate their contributions. The basic distinction between them is that in operant conditioning, an animal is allowed to move on its own and desirable behaviors are reinforced, while in classical conditioning, a stimulus and response are repeatedly paired and thus an association is formed without freedom of response in the animal.

5.5.1.1 Operant Conditioning. Operant conditioning is, for our purposes, the more important of the two learning models. It is any learning based on response contingent reinforcement. In other words, only one type of behavior is reinforced, therefore the animal learns to repeat the behavior, and performance is measured by the consistency or frequency of that behavior. So operant behavior is controlled by subsequent reinforcement or reinforcement contingent on execution of a prescribed behavior.

Reinforcement can be positive (reward) or negative. Positive reinforcement tends to increase the probability of occurrence of the behavior that precedes it, and the converse holds true for punishment. So positive reinforcement is useful in encouraging new behaviors or sequences of behaviors, and punishment is useful for eliminating unwanted behavior. Many subclasses of Operant conditioning exist. A relevant example is discriminative vs. nondiscriminative operant conditioning.

Nondiscriminative operant conditioning (simple reward training) involves giving positive (rewarding) reinforcement of a primary and/or secondary nature after a desired animal response. Primary positive reinforcements are unlearned rewards such as food, water, or petting. Secondary positive reinforcements are learned cues associated with primary reinforcement in the past. In discriminative operant conditioning, positive reinforcement also follows desired behavior, but only in the presence of a stimulus (verbal command, bell, light, etc.) that signals the availability of the primary reinforcement. Thus, the animal learns to respond only when the stimulus is given by the trainer, thereby bringing the response under the control of the trainer. For example, a dog can be nondiscriminatively trained to voluntarily sit at any time to obtain a food reward and discriminatively trained to sit only when a stimulus (the odor of explosives) is present.

Another relevant principle of operant conditioning is "shaping" or the method of successive approximations. In order to design a completely new

behavior, positive reinforcement is given in a series of successive steps such that a behavior is shaped, bit by bit, until the desired ultimate behavior is achieved. For example, to teach a dolphin to touch an object, the following successive approximation scenario might be used. After placing the object to be touched in the tank, the dolphin is positively reinforced every time it enters the general area of the tank. Soon, the dolphin will learn to spend most of its time in that area, and reinforcement can be restricted to when the dolphin moves within five feet of the object and is oriented toward it. Next, reinforcement is successively restricted to three feet, two feet, one foot, and finally, given only when the dolphin touches the object. Thus, by reinforcing successive spatial approximations, the ultimately desired behavior was eventually achieved.

The application of reinforcement immediately following a behavior is absolutely essential to operant conditioning. Conditioned stimuli or secondary reinforcers are thus useful in operant conditioning because timely primary reinforcement of a desired behavior is often not possible due to animal inaccessability (e.g., how do you immediately reinforce a cetacean for touching an object at a depth of 1650 feet?), but a secondary reinforcer (e.g., a transmitted tone) can provide this immediate reinforcement.

Partial reinforcement is another important tool in behavior modification. By rewarding every n^{th} response, or by rewarding a constant proportion of the responses on a random basis, behaviors tend to persist, i.e., resist extinction after removal of reinforcement, longer than behaviors that were reinforced after every response. Many schedules of intermittent reinforcement are possible and all help create consistent, reliable and durable behaviors.

5.5.1.2 Classical Conditioning. The essential components of classical conditioning are an unconditioned stimulus which produces an unconditioned response, and a conditioned stimulus that does not initially

produce the unconditioned response. For example, a dog naturally salivates (unconditioned response) when it sees its food (unconditioned stimulus). If a conditioned stimulus (a bell) is repeatedly presented immediately before and current with the conditioned stimulus (food), soon the conditioned stimulus (bell) alone will result in a response similar to the unconditioned response (salivating). So classical conditioning is the learning method by which conditioned stimuli become associated with unconditioned stimuli. This is how secondary reinforcers work, since secondary reinforcers are just conditioned stimuli that become associated with unconditioned stimuli (primary reinforcers). The secondary reinforcer, like the unconditioned stimuli, does not satisfy an innate need (e.g., food and water), but is effective in maintaining the conditioned response through previous association with the primary reinforcer.

5.5.2 Procedures

The following examples demonstrate the training principles just described as employed in previously used animal systems. The examples will serve three functions: provide clarification of the training principles already described, introduce some additional principles, and also provide more information on animal systems already mentioned.

5.5.2.1 Dolphins and Whales. The following scenario might be used for training a dolphin to report on the presence or absence of an object.[19,101,103-108] Initially, the dolphin is trained to station at some spatial point (e.g., a hoop) by operant conditioning and positive reinforcement. Next, a stimulus (an acoustic tone) is used to indicate to the animal when stationing is desired. That hoop serves as a discriminative stimulus which signals the animal that reinforcement will be forthcoming if the desired response is emitted.

The dolphin is next taught to report on the presence of an object by pressing on a paddle. This is accomplished by first shaping the paddle

pressing behavior and later giving positive reinforcement only when an object is present downfield. Another paddle can later be added for a "no object downfield" report. The reporting behavior is also put under the control of a discriminative stimulus (i.e., a different acoustical tone). Following this stage, the dolphin is taught by simple positive reinforcement to report more distant objects by moving the objects incrementally further away toward maximum range.

These behaviors can be chained together. "Chaining" is achieved by creating a situation in which the completion of each behavior in a series is both a secondary reinforcer for the completed behavior and a stimulus for initiation of the following behavior. Usually, when chaining behaviors, the final behavior in the chain is taught first, and behaviors that will precede it are each trained separately and added to the chain. Upon completion of a behavioral chain, a secondary reinforcement is usually given signaling the availability of primary reinforcement (food). Partial reinforcement can be used to extend the life of the response in the absence of reinforcement. So, upon delivery of an acoustic stimulus, the dolphin goes to station, scans the downfield area for the presence of an object, reports on paddles the presence or absence of the downfield object, then receives a food reward. This is an example of an in-pen task. An operational field system involves utilization and integration of other chains of behaviors, their number and complexity, depending on the task.

Two other techniques are useful in dolphin training. Prompting is simply using a previously established discriminate stimulus to hasten the shaping technique. For example, a dolphin taught to touch an acoustic beacon can be taught to swim through a gate (which they are reluctant to do) by placing the beacon to be touched successively further through the gate. Fading is another useful conditioning method used for transferring control over a response from one discriminative stimulus to another. An example is errorless reversal learning in the California sea lion.[109]

Finally, it is important to note the usefulness of a mild form of punishment for training animals. Removing the test equipment, trainer, and therefore, the source of food, from the pen is called a "time out," and can be very useful for eliminating undesired behavior or inappropriate responses.

5.5.2.2 Pigeon. During WWII, pigeons were trained by B.F. Skinner to track targets in order to supply on-board guidance to air-to-surface missiles.[25] The training was accomplished by methods already described, with shaping playing an especially prominent role. First, the pigeons were reduced to 80% of the free feeding weight to ensure food as an adequate primary reinforcer. The pigeon was then fitted with a harness around its neck that amplified the head movements into the gross movement of a hoist apparatus in which the pigeon rested.

A target was presented to the pigeon with its favorite grain at the bullseye, so by moving its head, the pigeon could reach the grain and eat. Tracking behavior was shaped by moving the whole hoist apparatus across a room toward the target in successively longer and faster runs. The pigeon learned to guide the hoist apparatus to the bullseye while it approached rapidly from different angles and distances.

A moving target was later projected on a screen directly in front of the bird, and the locus of pecking on the screen determined direction of guidance. Fading was used to facilitate this stimulus changeover. In addition, partial reinforcement was introduced to prolong the tracking behavior. In the final system, it was proposed that three birds be placed in the nose of the missile and their average output be used to guide it to the target. Tests showed excellent potential for the system, but it never reached operational status, apparently due to bias about the assumed absurdity of a "pigeon-guided missile."[110-114].

5.5.2.3 Dogs. The training of mine dogs is a good representative example of all dog training involving operant conditioning with food reinforcement. The object of training was a reliable detect, approach, and sit response within two feet of a buried mine.[77-83,115-125]

Dogs were obedience trained with typical classical and operant conditioning and both positive and negative reinforcement. Nondiscriminative operant conditioning followed. Mines were laid out in the open along a test course with a portion of food on each one. The dogs were allowed the freedom of finding the mines and food along the course, but if a mine was missed, the dog was walked back to make another pass over the area. At the rate of 48 trials (mines) per day, it took 4-8 days for the dogs to achieve a stable speed over the course. Next, partial reinforcement was introduced (only one-half the mines had food) and if mines were missed, the dogs were run through the previous learning stage again.

Once the course time had stabilized again, the dogs advanced to the next stage. A sit response was forced on the dog and immediately followed with food reinforcement at each mine. The dog was kept sitting until the command "move out" was given. If a mine was missed, the dog was walked back and put in a forced sit in front of it for one minute without reinforcement. When dogs were capable of six serial voluntary sit responses, they advanced to the next stage. In this stage, reinforcement was limited to voluntary sit responses within two feet of the mine and within six seconds of arrival, thus speed and proximity to the mine were shaped. After dogs achieved 9 of 12 correct responses on two consecutive runs, they advanced again. In order to remove the trainer from the dogs' immediate vicinity, the dogs were put on 25 foot leashes and given secondary reinforcement for appropriate responses. After a few problems, proficiency returned and the dogs were ready for more discriminative training. In the following six training stages, the stimulus mines were hidden in six increasingly difficult grades of concealment, and therefore the dogs were required to rely more and more on olfactory cues.

As a dog acquired proficiency at one grade of concealment, it advanced to the next. In 6-9 weeks, the dogs were capable of two 12-mine runs with only one bad response over a course of well concealed mines.

Finally, the dogs received 4-6 weeks of training in realistic field conditions. The seven month training program resulted in 14 mine dogs which were subsequently used in Vietnam with great success.[122,124,125]

5.6 REFERENCES

1. Lubow, R.E. The War Animals - The Training and Use of Animals as Weapons of War. Doubleday & Company, Inc., Garden City, N.Y. 1977.

2. Livy, The Early History of Rome. Books I-V of The History of Rome from Its Foundation. Translated by Aubrey de Selencourt. Baltimore, Md., Penguin, 1971, p. 393.

3. Encyclopaedia Britannica. Chicago: Encyclopaedia Britannica, Inc., 15th ed., 1975.

4. Levi, W.M. The Pigeon. Columbia, S.C., The R.C. Bryan Co., 1940, p. 3.

5. Cody, Martin, Professor of Ecology. Lecture Series at University of California, Los Angeles, Attended by Author, 1978.

6. Tomich, P.Q. Mammals in Hawaii, Bishio Muscum Press, Honolulu, 1969.

7. Pence, R.J. and Lomax, P. The Excised Bee Abdomen in Medical Research. The American Bee Journal, 1973 (December), Vol. 113, No. 12, pp. 460, 461, and 458.

8. Tatge, R.B. Forest Sound Spectrun Analysis, U.S. Army Limited War Laboratory, Aberdeen Proving Ground, Maryland, April 20, 1965, AD 618 082.

9. Barnhart, C.S., Sr., Krauss, M., Cole, M.M., and Mayer, M.S. The Use of Arthropods as Personnel Detectors. U.S. Army Limited War Laboratory, Aberdeen Proving Grounds, Maryland. September 1967. AD 820-550.

10. Barnhart, C.S., Sr., Cirads III Proceedings, Vol. 1. Sponsored by: Advanced Research Projects Agency, Contract No. F33657-67-C-0810, (December 1968), AD 845 300.

11. Licastro, R.H., Prodnax, L.D., and Byers, H.K. Potential of Ultrasonics to Provide Early Warning, U.S. Army Security Agency, Arlington Hall Station, Arlington, Virginia, Combat Developments Study No. CD-29-OJ, August, 1964.

12. Stager, K.E., 1964. The role of olfaction in food location in the Turkey Vulture (Cathartes aura). Los Angeles County Museum Contributions in Science, 81:1-63

13. Stager, K.E. Avian olfaction. American Zoologist, 7L415-419, 1967.

14. Droscher, V.B. The Magic of the Senses, E.P. Dutton & Co., Inc., New York, 1969, p. 101.

15. Schmidt, K.P. and Inger, R.F., Living Reptiles of the World. Doubleday, New York, 1957; Hamish Hamilton, Ltd., London, 1957, pp. 14-15.

16. Wood, F.G., Marine Mammals and Man - The Navy's Porpoises and Sea Lions. Robert B. Luce, Inc., Washington-New York, 1973.

17. Hersh, S.M. Chemical and Biological Warfare: America's Hidden Arsenal. London: MacGibbon and Kee, 1968.

18. Bailey, R.E., Training and Open Ocean Release of an Atlantic Bottlenose Porpoise Tursiops truncatus (Montagu), U.S. Naval Ordnance Test Station, China Lake, Ca., NOTS Technical Publication 3838, July 1965.

19. Conboy, M.E. Project Quick Find: A Marine Mammal System for Object Recovery. Naval Undersea Research and Development Center, San Diego, Ca., June, 1972.

20. Seiple, R.L., Quick Find Hardware for the Sea Lion Object Recovery System. Naval Undersea Research and Development Center, San Diego, Ca., NUC TN 492, January 1972.

21. This reference is available to qualified requestors.

22. Wood, F.G. and Ridgeway, S.H., Utilization of Porpoises in the Man-in-the-Sea Program in an Experimental 45-day Undersea Saturation Dive at 205 Feet. Office of Naval Research, Report ACR-124, 1967.

23. Bowers, C.A., Henderson, R.S., Deep Object Recovery with Pilot and Killer Whales, Naval Undersea Center, San Diego, Ca., AD 754-396, November, 1972.

24. Ching, G. and Porter, H.O. Project Deep Ops Equipment Development, Naval Underseas Center, San Diego, Ca., NUC TP 296, 1972.

25. Skinner, B.F. Pigeons in a Pelican. American Psychologist, 1960, 15, 28-37.

26. Verhave, T., The pigeon as a quality control inspector. American Psychologist, 1966, 21, 109-15.

27. Lubow, R.E. High-order concept formation in the pigeon. Journal of the Experimental Analysis of Behavior, 1974, 21, 475-83.

28. Herrnstein, R.J., and Loveland, D.H. Complex visual concept in the pigeon. Science, 1964, 146, 549-51.

29. Mallot, R.W., and Siddall, J. Acquisition of the people concept in pigeons. Psychological Reports, 1972, 31, 3-13.

30. Siegel, R.K., and Honig, W.K. Pigeon concept formation: Successive and simultaneous acquisitions. Journal of Experimental Analysis of Behavior, 1970, 13, 385-90.

31. This reference is available to qualified requestors.

32. General Altronics, training birds for field surveillance, Phase II, Final Report, April 15, 1965, Report No. 1404-2005-15, LWL 65-226.

33. Krauss, M. Ambush detection by pigeons contractor studies, U.S. Army Limited War Laboratory. Aberdeen Proving Ground, Md., Technical Memo No. 67-04, Interim Report, October, 1967.

34. Krauss, M., and Nichols, D.G. Potential applications of animals in unconventional warfare. Technical Note TN-6, USA Limited War Laboratory, AD 350-955, May 1, 1964.

35. Romba, J.J. Problems of controlled bird-flight, U.S. Army Limited War Laboratory, Aberdeen Proving Ground, Md., August 9, 1968, pp. 313-325, AD 837 165 L.

36. Romba, J.J. Ambush detection by pigeons: in-house studies: Achieving controlled bird flight, U.S. Army Limited War Laboratory, Aberdeen Proving Ground, Md., 21005, Technical Report 67-13, Nov., 1967.

37. Bernard, E.E., Research Planning Program for the Reconnaissance Pigeon. Technical Report AFAL-TR 179, August 1967, AD 818 502.

38. Holmes, S.C. Training birds for field surveillance. U.S. Army Limited War Laboratory, Aberdeen Proving Ground, Md., CRD-AM-7C. January, 1964.

39. Lubow, R.E., Siebert, L.E., and Carr-Harris, E. The perception of high order variables by the pigeon. Air Force Avionics Laboratory Technical Report, AFAL-TR-66-63, March, 1966.

40. Army, Field Manual, U.S. Army FM 7-42, Combat Tracker Dog Training and Employment, March, 1973.

41. Castle, L.J. Bloodhound: A tool in law enforcement. FBI Law Enforcement Bulletin, May, 1972, 1-5.

42. Schnitzer, S.B., Schnitzer, M.E., and Fuller, J.L. Studies on the tracking behavior of dogs, II Breed Differences in locating a hidden animal. R.B. Jackson Memorial Laboratory, Bar Harbor, Maine, 1956.

43. Carr-Harris, E., and Siebert, L. Off leash tracker dog - helicopter tracking team, Final Report, Technical Report No. LWL-CR-08B69, 1969. AD 858987 L.

44. Baker, Kemper, W., Squalene, marking tracking and identification, Final Letter Report to Chief, OSD/ARP A R&D Field Unit-Vietnam, San Francisco, Ca., June 1, 1966, Memo No. 945.

45. Whitlaw, J.T., Jr., Pratt, J.J., Jr., and Hilchey, J.D. Identification of squalene by dogs. Final Report, U.S. Army Natick Laboratories, Natick, Mass., Advanced Research Projects Agency, Washington, D.C., November, 1963.

46. King, E.J., Becker, R.F., and Markee, J.E. Studies on olfactory discrimination in dogs: (3) Ability to detect a human odor source. Animal Behavior (12) 311-315, 1964.

47. Lubow, R.E. On the problem of tracking artificially induced odors. Ministry of Police, July 15, 1974, Classified, 1-8.

48. Whitlaw, J.T., Jr., Pratt, J.J., Jr., and Hilchey, J.D. A study of the detection of chemically contaminated persons by dogs. Advanced Research Projects Agency, Washington, D.C., April, 1964.

49. Peters, A.C., and Allton, W.H., Jr., The use of marking agent for identification by dogs. Report No. BAT-171-40, Advanced Research Projects Agency, Washington, D.C., March 11, 1966, AD 278 125.

50. McHaffie, T.A. The use of dogs in searching for "pre-scented objects," Summary of Royal Air Force Work (1969).

51. Tomlinson, E.S. Field evaluation of dog countermeasure materials. Supplemental Report, U.S. Army Land Warfare Laboratory, Aberdeen Proving Ground, Maryland, Report No. 74-53, March, 1974.

52. Anonymous, Dogs detecting drugs. Bulletin on Narcotics, 28, pp. 41-60, 1976.

53. Dean, E.E. Behavior conditioning and training of dogs to detect heroin hydrochloride. Proceedings 1975 Carnahan Conference on Crime Countermeasures, University of Kentucky, May, 1975.

54. Gridgeman, N.T. Trials of the contraband screening abilities of six trained RCMP dogs. Division of Biological Sciences, National Research Council of Canada, Ottawa, 1972.

55. Knauf, H. and Johnston, W.H. Evaluation of explosives/narcotics (exnarc) detection dogs, U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia, May, 1974, AD 787 308.

56. Phillips, R.C. and Dean, E.E. Manual for training heroin search and detection dogs, Southwest Research Institute, San Antonio, Texas, 1973.

57. Romba, J.J. Training dogs for heroin detection, Technical Report - Interim 71-04, U.S. Army Land Warfare Laboratory, Aberdeen Proving Ground, Md., September 1971, AD 734 888.

58. Dean, E.E., and Phillips, R. Training dogs for narcotic detection, Technical Report LWL-CR-60DJ71, U.S. Army Land Warfare Laboratory, Aberdeen Proving Ground, Md., July 1972, AD 749 302.

59. Southwest Research Institute. Objectively evaluate the performance of dogs trained to perform various militarily significant tasks, Final Report, U.S. Army Mobility Equipment Research and Development Center, SMEFB-XE, Fort Belvoir, Virginia, Contract No. DAAK02-72-C-0132, December, 1972. AD 909 955 L.

60. Southwest Research Institute. Narcotic Explosive Detector Dogs, Final Report, SWRI 13-3095-2, January 1973. AD 756 939.

61. Blanchard, D., and Bradley, H.R. Canine detectors in narcotics control. The Police Chief, 36, (6), pp. 20-30, 1969.

62. FBI Law Enforcement Bulletin, January, 1976.

63. Romba, J.J. Letter to Constable Sheppard, Police Dog Service Royal Canadian Mounted Police, September 19, 1974, PI-10.

64. Halligan, W.A. Evaluation of familiarization and training in aircraft and airport environment for dogs trained in explosive detection measures, FAA Memo, October 19, 1971.

65. Morgan, P.M., Robinson, G.A.N., Yallop, H.J. The detection of explosives by dogs - trials in aircraft, Royal Armament Research and Development Establishment, Fort Halstead, Sevenoaks, Kent, England, RARDE Memorandum 29.73, December, 1973, AD 529 442.

66. Krauss, M. Explosives detecting dogs, Technical Report 71-11, U.S. Army Land Warfare Laboratory, Aberdeen Proving Ground, Md., September, 1971, AD 736-829.

67. Phillips, R.C. Training dogs for explosives detection. Technical Memorandum, LWL-CR-01B70, Aberdeen Proving Ground, Maryland, U.S. Army Land Warfare Laboratory, October 1971, AD 733 469.

68. Phillips, R., Lomax, R., Krauss, M. Draft information on training, use and maintenance of explosive detector dogs. Franklin Institute Research Laboratories, Philadelphia, Pa., January 1974. AD 777 499.

69. FBI Bomb Data Program, Use of dogs to find concealed explosives - update. General Information Bulletin, 76-1, 1976.

70. Gridgeman, N.T. Trials of the contraband screening abilities of six trained RCMP dogs. Division of Biological Sciences, National Research Council of Canada, Ottawa, 1972.

71. National Bomb Data Center, Use of dogs to find concealed explosives, General Information Bulletin, 74-4, Picatinny Arsenal, Dover, N.J., June 12, 1975.

72. New York City Policy Department, Explosive detection dogs, 10 pages, undated (about 1975).

73. Gage, H.M., Wall, W.A. An investigation of the sensitivity of trained detector dogs for vapors of the explosive ethylene glycol dinitrate, Army Land Warfare Laboratory, Aberdeen Proving Ground, Md., Technical Note No. 74-14, May 1974, AD 920 663L.

74. Knauf, H. and Johnson, W.H. Evaluation of explosives/narcotics (exnarc) detection dogs, U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia, May, 1974, AD 787 308.

75. Mitchell, D.S. Perform experimental and analytic studies to determine the olfactory sensitivity of various odor sensing animals. Final technical report. Southwest Research Institute, San Antonio, Texas. Sept. 1973, U.S. Army Mobility Equipment Research and Development Command Contract No. DAAK02-72-C-0602.

76. Southwest Research Institute. Narcotic Explosive Detector Dogs, Final Report, SWRI 13-3095-2, January 1973. AD 756 939.

77. Army Concept Team, Study and evaluations of countermine activities (SECMA), Volume 7, Booby Trap Countermeasures, Final Report, Dept. of the Army, Army Concept Team in Vietnam, APO San Francisco, Ca., ACTIV Project No. ACG-61F, 35 pp., 1968.

78. Boutineau, The mine clearing dog. Bulletin Technique du Genie Militaire. Third quarter, 1961, pp. 179-190 (translated for the U.S. Army Engineer Research and Development Laboratories Information Resources Branch by Scripta Technica, Inc.)

79. Carr-Harris, E., and Thal, R. Mine, booby-trap, tripwire, and tunnel detection, Final Report prepared for U.S. Army Limited War Laboratory, Aberdeen Proving Ground, Md., 1970, AD 867 404L.

80. Mitchell, D.S. Selection of dogs for land mine and booby trap detection training. Vol. 1, Final technical report. Southwest Research Institute, San Antonio, Texas. Sept., 1976. U.S. Army Mobility Equipment Research and Development Command Contract No. DAAK02-73-C-0150. AD-A031 980/6SL.

81. Marine Corps Development and Education Command, Final Report of USMC Project 90-69-01, Dog detection of mines/booby traps, Commandant, Marine Corps (Code AX), Washington, D.C., May 7, 1971 AD 883 469 L.

82. Nolan, R.V. and Gravitte, D.L. Mine-detecting canines. Report 2217, U.S. Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia. September 1977, AD-A048748.

83. Mitchell, D.S. Training and Employment of Land Mine and Booby Trap Detector Dogs (U), Final Technical Report, Volume II, U.S. Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia, September, 1976.

84. The Plessey Company, LTD. Cadavers detection study report. Report No. ERL/R 144U, Havont, Hampshire.

85. Walker, R.W. and Payne, D.C. The use of trained police dogs for corpse detection.

86. Drewett, R.J. Trials of specially trained police dogs. The Plessey Co., Ltd., Report No. ERL/R 24ZU, December 4, 1972.

87. Limited War Laboratory, Ambush Detection, Proceedings of a Symposium held at Aberdeen Proving Ground, Md., Technical Report No. TR-5, from U.S. Army Limited War Laboratory, Aberdeen Proving Ground, August, 1964.

88. Krauss, M. Training and evaluation of off-leash scout dog teams, Final Technical Report No. 67-10, U.S. Army Limited War Laboratory, Aberdeen Proving Ground, Md., August 1967, AD 385 200L.

89. This reference is available to qualified requestors.

90. McIntire, R.W. The training of dogs for field reconnaissance, Final Report, U.S. Army Limited War Laboratory, Aberdeen Proving Ground, Md., September, 1965, AD 476 427.

91. Tomlinson, E.S., Krauss, M. Night reconnoitering capability for military dogs, Final Report, U.S. Army Land Warfare Laboratory, Aberdeen Proving Ground, Md., Report No. 74-54, April, 1974.

92. Eisenhauer, P.M. Dogs for swimmer defense, Naval Ship Research and Development Laboratory, Panama City, Report No. NSRDL/PC-C3469, AD 517 324 L. Fla. September, 1971.

93. Lubow, R.W., Underwater Man-Detection System. For the Israel Ministry of Defense, June 1971, 1-7.

94. This reference is available to qualified requestors.

95. This reference is available to qualified requestors.

96. This reference is available to qualified requestors.

97. This reference is available to qualified requestors.

98. Weinstein, S. Further investigation of the neurophysiological procedures for detection of explosives. Final Technical Report, Contarct No. DAAG-53-76-C-0020, Fort Belvoir, Virginia, September 30, 1976.

99. Weinstein, S. Further investigation of the neurophysiological procedures for detection of explosives. Final Technical Report, Contract No. DAAG-53-76-C-0020. Fort Belvoir, Virginia, December 30, 1977.

100. Weinstein, Sr., Weinstein, C.D., and Nolan, R.V. Neurophysiological operant and classical conditioning methods in rats in the detection of explosives. Paper presented at Third Annual Meeting of the Role of Behavioral Sciences in Physical Security. National Bureau of Standards, Arlington, Virginia. May 2-4, 1978.

101. Pepper, R.L., and Defran, R.H. Dolphin Trainer's Handbook, Part I. Basic Training. NUC TP 432, Naval Undersea Center, San Diego, Ca., April, 1975.

102. Holland, J.G., and Skinner, B.F. The Analysis of Behavior: A Program for Self-Instruction. McGraw-Hill Book Company, Inc., New York, 1961.

103. Beach, F.A. III and Pepper, R.L. Marine Mammal Training Procedures: The effects of schedules reinforcement in the dolphin (Tursiops truncatus). Naval Undersea Research and Development Center. January 1971, NUC TP 214.

104. Irvine, B. Conditioning marine mammals to work in the sea. Marine Technology Society Journal, 1970, 4, 47-52.

105. Hall, J.D. Conditioning pacific White-striped dolphins, Lagenorchychus obliquidens, for open-ocean release. Naval Undersea Research and Development Center, Aguust, 1970. NUC TR 200.

106. Irvine, B. Conditioning marine mammals to work in the sea, Marine Technology Society Journal, 1970, 4, 47-52.

107. Malinov, A. and Lebeder, L. Dolphin Training. Trans. of Nedelya (USSR) n37 pp. 6-7, September, 1974.

108. Steele, J.W. Marine environment cetacean holding and training enclosures. Naval Undersea Center, San Diego, Ca., NUC TP 227, 1971.

109. Schusterman, R.J. Attention shift and errorless reversal learning by the California sea lion, Science, May 12, 1967, Vol. 156, No. 3376, pp. 833-835.

110. Chernikoff, R., and Newlin, E.P., ORCON, Part III, Investigation of target acquisition by the pigeon. Naval Res. Lab. Lett. Rep., 1951, No. S-3600-629a/51.

111. Conklin, J.E., Newlin, E.P., Jr., Taylor, F.V., and Tipton, C.L. ORCON, Part IV., simulated flight tests. Naval Research Laboratory Rep., 1953, No. 4105.

112. Searle, L.V. and Stafford, B.H. ORCON, Part II, Report of phase I Research and bandpass study. Naval Res. Lab. Lett. Rep., 1950, No. S-3600-157/50 (May 1).

113. Taylor, F.V. ORCON, Part I. Outline of proposed research. Naval Res. Lab. Lett. Rep., 1949, No. S-3600-157/50.

114. White, C.F. Development of the NRL ORCON tactile missile simulator, Naval Res. Lab., Rep., 1952, No. 3917.

115. Carr-Harris, E., Siebert, L. Thal, C., and Thal, R. Mine, Booby-Trap, Trip-Wire Detection Training Manual. Contarct No. DAAD05-69-C-0234. Behavior Systems, Inc., Raleigh, North Carolina, September 1969.

116. U.S. Army Limited War Laboratory. Tunnel and Trip-Wire Detecting Dog-Handler Teams. Operating Manual. U.S. Army Limited War Laboratory, Aberdeen Proving Grounds, Maryland. April 1969.

117. U.S. Army Limited War Laboratory. Mine, Booby-Trap and Trip-Wire Detection Dog-Handler Teams. Operating Manual. U.S. Army Limited War Laboratory, Aberdeen Proving Grounds, Maryland. April, 1969.

118. U.S. Army Limited War Laboratory. Mine, Booby-Trap and Trip-Wire Detecting Dog-Handler Teams. Operating Mnaual. U.S. Army Limited War Laboratory, Aberdeen Proving Grounds, Md., April, 1969.

119. Army, Field Manual, U.S. Army FM 7-41, Mine and Tunnel Dog Training and Employment, March, 1973.

120. Anonymous, Army Considers Ambush Detection Dogs, Army Research and Development Newsmagazine, P. 7, October, 1965.

121. Mitchell, D.S. User's guide: Land mine and booby-trap detector dogs. Vol. 3 Southwest Research Institute, San Antonio, Texas, September 1976. U.S. Army Mobility Equipment Research and Development Command Contarct No. DAAK02-73-C-0150.

122. Carr-Harris, E., Siebert, L., Thal, C., and Thal, R. Mine, Booby-trap, Trip Wire and tunnel detection. Final Report prepared for U.S. Army Limited War Laboratory, Aberdeen Proving Ground, Md., 1970, AD 867 404L.

123. Lucero, D.A. Monthly report of Marine Corp., Mine Detection Dog Program, 3rd Military Police Battalion Force Logistic Command, Fleet Marine Force Pacific FPO, San Francisco, Ca., April 1, 1970.

124. Marine Corps Development and Education Command, Final Report of USMC Project 90-69-01, Dog detection of mines/booby traps, Commandant, Marine Corps (Code AX), Washington, D.C. May 7, 1971, AD 883 469L.

125. White, B.O., Jr., Army concept team in Vietnam, 60th Infantry Platoon (scout dog) (Mine/tunnel detector dog), Final Report, January 2, 1970.

6.0 RECENT RESEARCH, DEVELOPMENT, AND OPERATIONAL USES OF ANIMALS

6.1 APPROACH

The information presented in this section was obtained from a variety of sources. The authors of this report either knew of work going on or were put in contact by the sponsor with personnel in various government agencies currently working on animal capabilities research or systems developments. Some of these people were interviewed and documents on their work and those of others were obtained. They also provided additional contacts.

Also, search was made through the Defense Documentation Center of the Research and Development Planning Summaries (DD Forms 1498). The search request stated that the information desired was "work in the area of biological phenomena, biological systems, animals, marine mammals, birds (pigeons and others), etc." The forms received as a result of the search were reviewed. Virtually none of the projects cited were relevant to systems application of animals. Many of the citings were for projects concerned with such topics as bio-medical research, microbiology, and physiology. There were numerous projects in which animals were used in the study of radiation, chemical, rapid acceleration/deceleration, and other hazards. Also excluded from write-up in this section are those projects concerned with bio-degradation of materials (except oil spills) and marine biology (deep scattering layer, benthic organisms, phytoplankton, etc.)

Relevant findings were organized and are presented below according to the types of animals investigated or used.

6.2 DOGS

The Air Force has the responsibility for training the dogs used by all of the armed services. The dogs are trained at the Military Working Dog

Center, Lackland Air Force Base, Texas. There are facilities for maintaining and training over 300 dogs at the Center. Dogs and their handlers are trained for patrol and narcotics or explosives detection. The course is nineteen weeks long. The teams are trained for vehicle, aircraft, and building searches. Some dogs have also been trained for personnel tracking. The cost of training a dog and his handler has been estimated at between $8,000 - $10,000 exclusive of land, building, and capital equipment costs.[1] The Center at Lackland AFB also conducts some research studies. In 1975 a study was initiated to compare the odor detection capabilities between German Shepherd dogs and four small breeds of dogs. The German Shepherds were compared with Cairn Terriers and Beagles for drug detection and with Schnauzers and Fox Terriers for explosive detection. The performance differences were not statistically significant.[2]

The Army no longer has any operational mine detection dogs. The Army's dog research program was terminated in 1975. Also, the breeding program at Edgewood Arsenal, directed by the Surgeon General's office, has been shut down. Some of the breeding stock is now at Lackland Air Force Base. However, the Air Force does not breed its own dogs. Dogs, mostly of German Shepherd stock, are carefully screened and purchased from the public.

The U.S. Customs Service trains dogs at Front Royal, Virginia, for detection of narcotics. The program was started in 1970 at Lackland AFB and moved to the Customs Service's own facility in 1974. Approximately 40 dogs are trained each year. The animals are trained to detect hashish, marijuana, new heroin, old heroin, and cocaine. The conditional response to detection is to attack the container in which the contraband is concealed. (The Air Force program conditions a sit response.) Some of the Customs Service dogs have been tried out by the Coast Guard. However, successful use of the animals requires adaptation to working in a shipboard environment. Customs also has an explosives and firearms detection course. There is an experimental program to train and evaluate dogs for border patrol and narcotics detection.[3]

The Federal Aviation Administration utilizes dogs for bomb detection. There are about a dozen dog teams scattered about the country in cities with major airports. These have been trained for the FAA by the DOD Dog Center at Lackland Air Force Base. The dogs are maintainted by city police forces but are on call for use by the FAA when needed. Dog handler teams are stratigically placed so that a commercial airliner could reach an airport with a team within 30 minutes flight time anywhere in the continental United States.

It is understood that the Secret Service has trained its own patrol and explosives detection dogs.[1]

Under sponsorship of the Department of Energy, canines from the Military Working Dog Center have been evaluated for explosives detection at the Allied-General Nuclear Services research and development facility in Barnwell, South Carolina. The explosive samples used were dynamite, C-4, and TNT. Most of the work focused on detection of explosives on personnel. Booths about the size of telephone booths were placed in a passageway. The person to be inspected stepped inside the booth. Air flowed down from the top of the booth, over the person, and out a duct at the bottom. The dogs sniffed the exhausted air and gave a sit response if they detected explosives. Subjects were randomly given a sample of explosives (10 oz of dynamite or 4 oz of C-4 or TNT) before entering the booth. Two dogs were used in the tests. A thousand trials were run. The probability of detection obtained was .96. False alarm rates varied between 5 and 6.8%.[4]

The capability of dogs, and for that matter other animals, for drug and explosives detection is controversial. Those who have trained the animals and operational personnel utilizing them attest to their value. Incidents are related in which "hits" have been made on stashes which otherwise would have gone undetected. On the other hand, some physical chemists and hardware oriented researchers claim that the studies run by behaviorists often are poorly controlled. One objection is that during

tests the dog handlers often know in which containers the stimulus material has been placed, and they may inadvertantly be cueing the animals. In some cases the outsides of containers may be contaminated. With respect to detection of dynamite, it has been hypothesized that the animals may be detecting the fillers, such as peanut shells or apricot pits (which may vary from batch to batch) rather than the active ingredient, ethylene glycol dinitrate (EGDN), which remains consistent. In most animal experiments the concentration in the air of the stimulus being presented to the animal has not been quantified. In defense of the behaviorist it must be said that such quantification is extremely difficult. EGDN molecules are very sticky. It is hard to determine how many are getting through the container walls or sticking to the walls of experimental apparatus, and how many are in the sample of air being sniffed by the animals. For the same reasons, it is difficult to provide uncontaminated air samples for control trials. In general, instrumentation with the sensitivity, discriminability, mobility, and ease of operation of dogs is not available. That is why the animals are used.

6.3 RODENTS

6.3.1 Stress Detection

A report from Canada related that gerbils were trained to detect small amounts of epinephrine, a hormone associated with stress response in humans.[5] The subject placed his hand in a box over another box containing the gerbil. The animal sampled the air passing over the subject's hand and reported detection of a stress odor or non-stress odor. The reference states that the approach was "tested in various Canadian government operational settings with highly favorable results."

6.3.2 Explosives Detection

Gerbils have also been trained to detect the odor of an explosive and were shown to be capable of detecting TNT, EGDN, PETN, C4, CIL 40% Forcite, DNT, RDX, Deta Sheet, and two potential taggants, SF6 and CBr_2F_2.

It was stated that the behavior was learned in fairly few trials and performance was at the 85% to 95% detection level. These experiments were qualitative in that the concentration of the odorant in the air sampled by the animals was not determined.

Subsequently, vapor sources were developed which enabled quantification. It is reported that gerbils detected dynamite at the 0.4 ppt level, DNT (dinitrotoluene) at 1 ppb, and TNT (trinitrotoluene) at 0.05 ppb. No effort was made to find the lowest level.[6] In all of these experiments with gerbils, the animals were motivated by application of a mild footshock (about 0.8 mA) which their responses to the odor stimulus presentation terminated. The laboratory equipment used in the quantitative studies was modified and tested by Canadian government personnel with reportedly great success.[7]

The Federal Aviation Agency in the United States wanted to verify the results of the experiments in Canada. A contract was awarded to Dr. David Moulton at the University of Pennsylvania. He is conducting carefully controlled experiments to determine the performance of gerbils in detecting EGDN. Results of those experiments will be forthcoming in about a year.[8]

Previous work by Moulton with rats indicated that their threshold for detecting EGDN is one part per million. Detection of taggants (additives to improve the detectability of explosives or aid in source identification) and concealment of the EGDN odor also was of interest. This work was sponsored by the Bureau of Alcohol, Drugs, and Firearms in the Department of the Treasury and under direction of a physical chemist at the Aerospace Corporation.[9]

6.3.3 Electroencephalographic Response. The Army has been conducting experiments to determine if the brain waves of conditioned rats can be monitored to detect explosives.[10] In these experiments electrical brain stimulation was given for positive reinforcement rather than food rewards. An electrode was placed in the Medial Forebrain Bundle (MFB) of each

experimental animal. Operant conditioning was used to shape a lever pressing response with the electrical brain stimulation used as a reward. Stimulation parameters were optimized.

In some experiments, discriminant operant conditioning was used first to obtain a lever pressing response to the presence of the odorant in TNT. Then the brain waves were observed. In other experiments, using classical conditioning methods, no lever pressing response had to be trained. The rats showed differences in the brain wave measurements between baseline and TNT exposure and between pre-TNT and TNT exposures.

Work is continuing to verify the optimal position of the cortical frequency spectrum measurement (CFS - brain wave measurement) electrode to determine specific features of the CFS which indicate the presence of TNT so that these can be incorporated in a microprocessor algorithm.

One of the reasons offered for use of the CFS rather than requiring a trained behavior response (lever press) is that CFS changes vary in degree. This allows probability estimates to be made of the presence of the explosives and opens the possibility of gradient searches to lead one to the precise location of the package. In contrast, a lever pressing response is binary. The latency of the CFS response is also shorter than lever pressing.

6.4 BIRDS

6.4.1 Search System

In a project called Sea Hunt, a system was developed to make use of pigeons in daytime search and rescue missions. Pigeons were trained to peck a key when international orange, yellow, or red objects (e.g., life vests or rafts) are sighted on the open ocean. In operational use, three pigeons are housed in an observation chamber attached to the bottom of a helicopter. Each pigeon is in a separate compartment and has a field of view in the horizontal plane of 200°. The centerlines of the compartments are 120° apart. This arrangement provides six viewing areas, three

of which are each unique to one pigeon and three of which overlap for viewing by two birds. When one or more of the pigeons detects a target on the water and pecks its key, a light goes on in the cabin alerting the flight crew to a detection and providing general directional information.

The system described above makes use of the pigeons' superiority over man in performance of visual searches. Because of retinal structure and behavioral factors the pigeon is able to process acute visual information simultaneously over a much larger portion of the visual field than man.[11] Furthermore, pigeons will remain attentive to the search task for longer periods.

In field studies with the system, the pigeons detected targets 90% of the time on the first pass over the target as compared to 38% for the three or four man flight crew. On those trials in which the target was detected on the first pass by either the pigeons or aircrew, the pigeons were the first to see the target 85% of the time. In considering those data, one should also note that (1) on those trials in which the pigeons detected before the human observer, the aircrew was then told where to look, and (2) the aircrew knew the approximate location of the targets and could relax between trials.

Sponsorship of the project has now been assumed by the Coast Guard which is supporting development of the system for operational use.

6.5 MARINE ANIMALS

The Naval Ocean Systems Center has been involved in research and development with marine mammals for over twelve years. Two of the Navy's marine mammal object recovery projects were described previously. The operational system, Quick Find, has been used to make 40 successful test ordnance recoveries up to October 1979.

Behavioral research is also being conducted at the Naval Ocean Systems Center (NOSC). Additional information is being obtained on the capabilities of a variety of species of marine mammals, and training technologies are being advanced. Two studies involve determining whether a dolphin can report on several attributes of a target instead of just reporting whether or not a specific target is present. Another project was concerned with extending reinforcement schedules on a detection task. It was found that detection performance could be maintained even though a trained animal was rewarded only on the average of once every fifty trials. This finding is important if animals are used for tasks in which they have to work for many hours, do not have to respond frequently, or perform at some distance from an operator who can provide the rewards. A matching-to-sample echolocation experiment was conducted and indicated that a blindfolded dolphin can easily grasp the concept of "sameness versus difference" of two targets.

The Navy's biomedical support work includes developing methods for: obtaining healthy animals, stress reduction, and medical monitoring. Work on stress reduction involves development of medication/sedatives for use when animals must be removed from the water for examinations, medical care or transport. Medical monitoring techniques are being developed to identify sick animals and diagnose their ailments. One approach being studied is to analyze the sound production of the animals and attempt to identify those sounds which indicate distress. Research is also underway in immunology, vaccines, and treatment methods. Nutritional studies have been conducted for several years. One goal is to develop a ration which can be easily prepared and transported so that a local supply of fresh fish is not required to support animals being employed away from their home base. Techniques are being developed for improving the breeding of animals in captivity and for screening wild animals. In the breeding program more is being learned about requirements for housing and care of pregnant animals

and about how to rear offsprings. Procedures are being developed for monitoring the young, detecting premature births, and diagnosing and treating illness in mothers and offsprings. Emphasis has been on the reproduction of Tursiops truncatus. Knowledge on the breeding of that species has also been contributed by oceanariums. The San Diego Zoo Research Department, sponsored by NOSC, succeeded in inducing ovulation in captive dolphins.[12]

6.6 SHARKS

Most of the past research on sharks had been directed towards trying to understand their behavior and developing methods to protect people from shark attacks. Funding of that work, sponsored mainly by the Office of Naval Research, has declined over the past several years.

In the past year personnel of the Naval Ocean Systems Center have been investigating the trainability of sharks. Two nurse sharks have been trained to station in front of their trainer and accept food. They will also retrieve an object placed in their tank. While showing promise, work on training sharks to perform useful tasks is still in the early stages of development.

6.7 BACTERIA

6.7.1 Biodegradation of Oil[13]

The Navy has sponsored research on utilizing bacteria to break down oil in ships' bunkers and bilges and from spills. The research revealed that appropriate bacteria were already present in those areas, but the process was too slow. Nitrogen, phosphate, and oxygen were added to accelerate biodegradation, but it was still not fast enough for shipboard purposes. Also, in the bilges, there were too many toxic substances

for the bacteria to work effectively. Only when oil gets into inaccessible areas such as among pilings or in swamps or mangroves, where containment and vacuuming is difficult, might the facilitation of biodegradation be worthwhile.

6.7.2 Bacterial Luminescence for Toxicity Determination

A system which uses luminescent marine bacteria for rapid bioassay of water samples is commercially available.[14] To test a water sample, frozen dried cells of the reagent culture are rehydrated and put in a special light measuring instrument. Comparisons are made between baseline light output readings and readings five minutes after the water samples have been added. As light output is a measure of the health of cells, a decrease in light output is a measure of the toxicity of the sample solution. Pure compounds and complete effluents can be tested. Results compare favorably with the typical fish lethality assays which take from 24 to 96 hours and are quite costly.

6.8 REFERENCES

1. Interview with Lt.Col. Daniel J. Craig, Military Working Dog Center, Lackland Air Force Base, 30-31 January 1980.

2. Lt. Col. Craig, Dan J. "Small Breed Detection Dog Study." In: Proceedings: New Concepts Symposium and Workshop on Detection and Identification of Explosives sponsored by U.S. Department of Treasury, Energy, Justice, and Transportation. October 30,31 and November 1, 1978. Reston, Virginia.

3. Telephone conversation with Tom Chowning, U.S. Customs Service, Front Royal, Virginia. 23 January 1980.

4. Smith, James C., Studies and Research Concerning BNFP: Testing the Use of Canines for Personnel Explosives Screening and Other Physical Protection Related Activities, Final Report, AGNS-35900-2.15, Allied General Nuclear Services, Barnwell, South Carolina, November 1979.

5. Biederman, G.B. "The detection of stressful individuals: a feasibility study." Committee of Aviation Security, National Research Council of Canada, Report No. CAS 74/6, 1974. As cited in reference 7 below.

6. Biederman, G.B. "Detection of explosives by animals in an automated setting: II. A quantitative laboratory investigation." Committee on Aviation Security National Research Council of Canada. Report No. CAS 77/6, 1977. As cited in reference 7 below.

7. Biederman, G.B. "The use of small mammals in explosives detection." In: Proceedings.....Op. Cit. (ref. 2 above).

8. Verbal communication with Mr. Gerald Carp of the FAA, Washington, D.C.

9. Verbal communication with Mr. Dan Lucero, Aerospace Corporation, Washington, D.C.

10. Nolan, R.T., Weinstein, S., and Weinstein, C. "Electroencephalographic studies of specially-conditioned explosives detecting rats." In: Proceedings......Op. Cit. (ref. 2 above).

11. Simmons, J.V., Jr. Project Sea Hunt-FY78 Final Report. Technical Report 414. Naval Ocean Systems Center, San Diego, California, March 1979.

12. Kirby, Vicky. Induced Ovulation in Captive Atlantic Bottlenose Dolphin, Tursiops truncatus. Paper presented at the 1979 Annual IMATA Conference, San Diego, California, November 1979. Work performed by San Diego Zoo Research Department in conjunction with the Naval Ocean Systems Center.

13. Conversation with Dr. Arthur Emory, Jr., Biological Sciences Division, Office of Naval Research, Arlington, Virginia.

14. Beckman Microtox Model 2055 Toxicity Test Analyzer System.

15. Bulich, A.A., Greene, M.W., and Isenberg, D.L. The Reliability of the Bacterial Luminescence Assay for the Determination of Toxicity of Pure Compounds and Complex Effluents. Beckman Instruments, Inc., Carlsbad, California.

7.0 CONSIDERATIONS IN DEVELOPMENT AND USE OF ANIMAL SYSTEMS

7.1 WAYS OF USING ANIMALS

When considering ways in which man can be aided by animals, the tendency is to focus on a few well-known approaches employed successfully in the past. While those approaches will be explored thoroughly in this study, the whole range of possibilities will be considered. Those possibilities are identified in Figure 8 and described below. When past and current uses of animals are discussed later in this report, the specific combination of alternatives for each system will be apparent.

7.1.1 Trained Animals

Most animal systems use animals which are trained in captivity. There is also the possibility of training animals in their natural habitats.

7.1.1.1 Trained in Captivity. By far, the overwhelming number of systems employ animals from already domesticated species. The animals are bred or selected for characteristics particularly suited to the purpose for which they are used. The animals are trained in captivity. During use, an animal may be in an enclosure. A guard dog in a building or fenced compound exemplifies that kind of system. Alternatively, the animal may be loose during all or part of the mission (but still under behavioral control). Such an implementation is illustrated by a carrier pigeon which flies from its release point to its home coop.

Also, it may be feasible to train an animal in captivity and then release it to maintain itself in the wild. Subsequently, the animal would be available for use in the wild, or it might be recalled for use in captivity. For example, a marine mammal could be trained in captivity to dive to a particular depth when it received a command signal. After

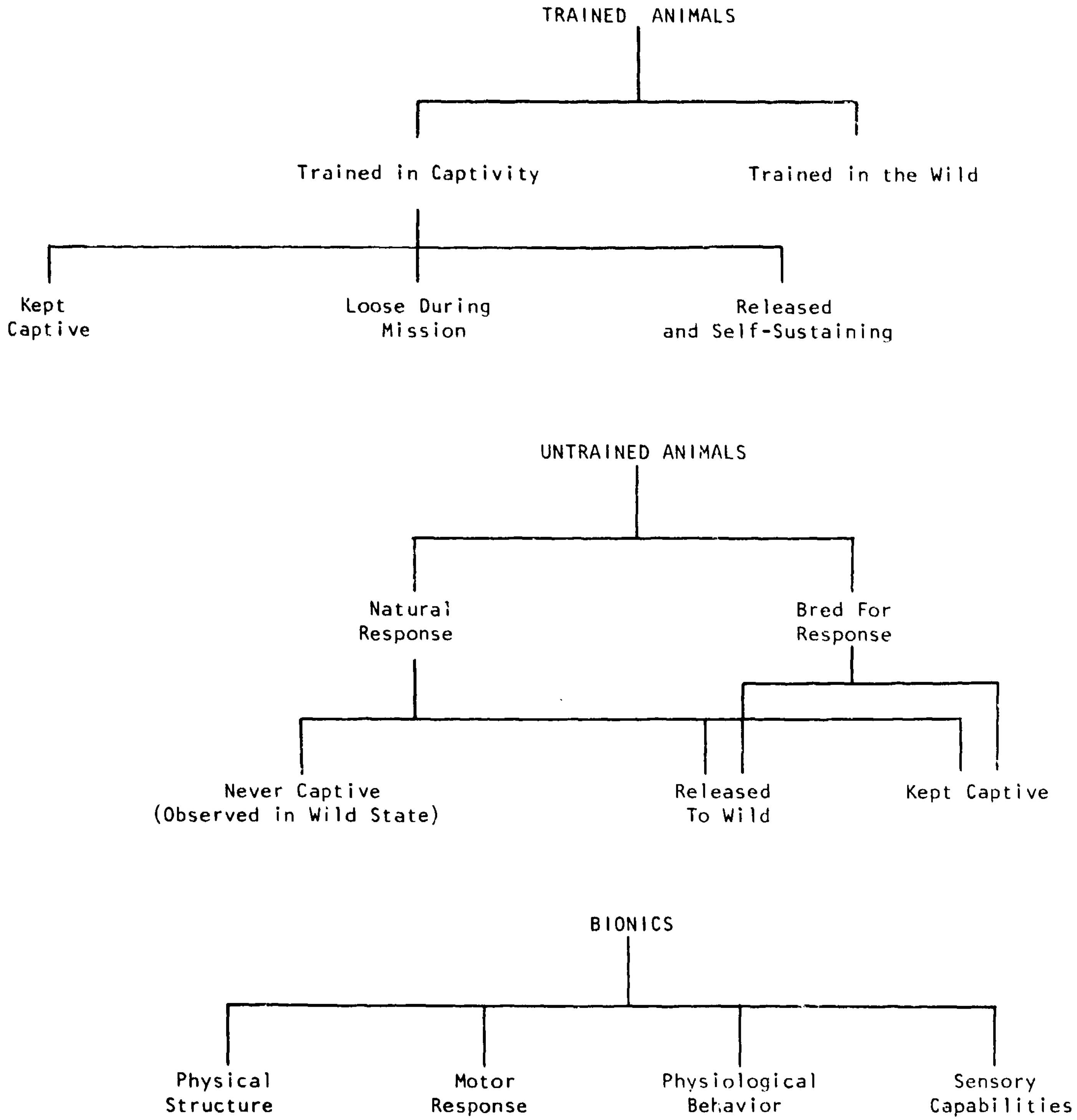

Figure 8. Ways of Using Animals

training, the animal is released with an instrumentation package attached and lives a natural life in the wild. Periodically, a signal is transmitted to the animal, and it responds by diving to the commanded depth. The measurements taken by instruments in the package are automatically transmitted to a satellite or shore base when the animal surfaces. No systems of this type were identified in the course of this project. There are, however, similarities with systems which use untrained animals. (See 7.1.2 below.)

A potential problem with training an animal in captivity and then releasing it is that the animal may no longer be capable of sustaining itself in the wild. Additional conditioning may be required to teach the animal to survive in its natural habitat. For example, the animal may have to be taught to hunt for food.

7.1.1.2 Trained in the Wild. To perform some missions, it may be possible to train animals in the wild, e.g., without ever capturing them. During World War II, the British conditioned sea gulls to gather over submerged submarines by releasing garbage from their own submarines traversing the English Channel. In general, this approach is most applicable where a large number of animals can or must be trained on very simple behaviors. It could also be used when a very large, costly to maintain animal (e.g., a whale) would be useful.

7.1.2 Untrained Animals

Training is not necessarily required to make use of animals in a system. The natural, predictable response of an animal to a particular stimulus can be exploited. The use of canaries to detect gases in coal mines exemplifies such an approach. In that case, the response (death) is quite apparent, but the responding animal cannot be used again. A common use of untrained animals is to capture some, put transmitters on them, and then track them to learn their migration and other behavior patterns.

Animals can also be selectively bred to obtain the behavior desired for use in a system. With lower orders of animals in which reproduction rates are very high, selective breeding may be rapid and not too costly. Mutagens also can be used with those lower animals to increase the variety of physical and behavioral characteristics from which to choose.

There are three options with respect to restraint of the untrained animals for system utilization. They may be kept in captivity, raised in captivity, or captured and then released to perform, or simply observed in the wild. Releasing captive animals to the wild may result in the survival problem discussed previously. Observation of wild animals to detect or predict a change in the environment (e.g., the coming of winter) is probably the oldest use of animals (other than eating them) by man.

As with the use of trained animals, there is a variety of options for incorporating hardware into the systems contemplated for utilizing untrained animals.

7.1.3 Hardware Utilization

Certainly there will be hardware and instrumentation used in many proposed systems. In some cases the hardware will be in the animal's enclosure; in other uses the animal may go to the hardware. Of course, hardware may be used to enclose, restrain, transport, support (e.g., feed), present data to, transmit data from, or process and display data from an animal. Some hardware may be used in training an animal but not employed in the operational system.

An important consideration in system concept formulation is whether devices are carried by, strapped onto, or surgically implanted in the animal. Such devices might:

- Sense features in the environment
- Detect, transduce, and transmit animal behaviors or physiological responses
- Be manipulated by the animal
- Be operated remotely by man or operate automatically.

The interaction between hardware construction and animal behavior conditioning in system development is important. Animal training may be held up by the time lags in building system hardware which are also used as training aids. Also, equipment design or operating deficiencies can create training problems. Often hardware design requirements change as the trainers observe the use of equipment by the animals and encounter training problems.

Of course, the effect of system hardware on animal mobility and behavior is vital to system effectiveness. While for some systems it is acceptable or desirable to constrain an animal, in others, full use of the animal's speed, endurance, or diving capabilities is desired. Another consideration is the possible effect that wearing of equipment by one animal will have on other animals with which is must interact. An animal which looks or acts differently may be subject to attack or exile by others.

7.2 SYSTEMS CRITERIA AND CONSIDERATIONS

In this section we discuss many of the criteria and factors which need to be considered in making a decision as to whether or not to pursue research and development on an animal system. It is obvious that most of the considerations are common to any system development. Still, it is worthwhile reviewing the criteria and keeping them in mind for evaluating ideas for uses of animals by the Coast Guard suggested later in this report or on any subsequent occasion. Caution must be observed not to overemphasize a single criterion to the exclusion of others. A low grade on any of the evaluation measures can be the basis for excluding a system from further consideration or for drastically revising the system concepts.

7.2.1 Acceptability

In addition to performing a mission well, the selected animals must be acceptable to Coast Guard operating and management personnel. The public and cognizant government organizations (especially Congress) must also feel positive about the use of the animals for particular purposes. For example, a pig might be able to perform a critical function very well for the Coast Guard, but could Coast Guard personnel accept the image of working with that species? Would there be derisive expressions from the public and rejection of the system by Congress? Those types of questions must be answered specifically for each system proposed. A great deal depends on how public and government interbody relations are handled and on the mood of the times.

7.2.2 System Development Risk and Producability

Incomplete knowledge of selected species and other uncertainties create risk in launching a system development effort. System development may not be warranted until additional research increases the knowledge and technology base and reduces that risk to an acceptable level. Some of the same factors which create risk in developing a system also influence the capability to produce the quantity of units of a system which are needed.

7.2.2.1 Technology State-of-the-Art. Besides knowledge of performance capabilities for which a species may be chosen, there must be sufficient information about the life support requirements and overall behavioral patterns of the species to insure that its use for a system application can be sustained. Adaptability of a species to the different environments in which it may be desirable to use that animal is an important factor to consider. Although there are general principles of learning and training, the procedures for training different species may vary widely. For example, predatory animals may eat infrequently and food cannot be used as readily to reinforce desired behavior. A proposed system concept also may impose demands on engineering technologies which are beyond the state-of-the-art.

7.2.2.2 Animal Obtainability. There must be a way of insuring that the number of animals needed to develop and use the system can be obtained. In some cases, e.g., endangered species, there will actually be legal constraints on obtaining or working with the species desired. Given that there are no legal barriers, a reliable, economic source of the animals must be assured. Setting up breeding colonies may solve that problem for some systems. However depending on reproductive habits, gestation period, litter size, time to wean offsprings, and other factors, such an approach may or may not be attractive.

7.2.3 System Cost-Benefits

The primary concern here is how well the system as it is perceived to operate will perform the mission(s) for which it is designed. There is also the question as to whether or not the results will be worth their cost. Mission importance and the likelihood or frequency that a system will be used also are trade-offs in a system development decision. It may be worthwhile to develop a system to perform a relatively insignificant mission if such a system would ease the burden of a frequent nuisance.

The development of an animal-centered system must be weighed against the possibilities of building hardware systems to perform the same functions. To formulate worthwhile concepts for performing a mission with animals, the mission should be thoroughly analyzed. During that analysis, new ideas may occur for performing the mission with hardware. Those hardware alternatives may be highly competitive with the proposed animal system.

Some of the factors which go into determining a system's mission cost-effectiveness are discussed below.

7.2.3.1 Versatility. Coast Guard units tend to be multi-mission oriented. In contrast, it will be seen that many animal systems are designed to fulfill very specific functions. If a system is used with frequent regularity in its primary role, limiting it to that role may be perfectly

satisfactory. On the other hand, if a system is only employed occasionally for its primary role, giving that system greater versatility may provide more opportunities for its employment.

7.2.3.2 Availability refers to the system's being ready to use when and where it is needed. Reliability relates to how often the system will break down when it is in use. Maintainability is how long it takes to get the system operational again when it has malfunctioned. The combination of reliability and maintainability yield a percentage of time during which the system can be used effectively. Those factors apply as much to the animal behavior aspects of a system as they do to hardware elements.

Response time for the system to be transformed from a quiescent state to operational readiness at the location where it is to be employed is another factor impacting on system availability. Mobility of the animal system relates both to time to get to and performance in an operational area. In some situations the animal may provide its own mobility. More often the animal will have to be transported along with system personnel and hardware to where it is to be employed. Once the system arrives at the operational site, some time may be required to get it ready to use. With animal systems, an important consideration is whether the animal has to be acclimated, physiologically or behaviorally, to a new, unfamiliar location. New sounds, odors, different temperature, or unfamiliar physical configurations of objects (e.g., machinery, stairs, passages, etc.) may be aversive to an animal or create task performance problems. Careful design of a system and conditioning the animals to work in a variety of environments may alleviate these problems.

Legal constraints may also impact system mobility. It may be illegal to bring some types of animals to certain locations (e.g., gerbils in California or snakes in Hawaii).

7.2.3.3 Performance. At the heart of system evaluation is the appraisal of a system's performance as predicted prior to system development and as measured subsequent to development. Different performance criteria will be applicable to different types of systems. For search systems, a common employment of animals, such measures of performance as probability of detection, area search rate, and false alarm rate will be applicable. The consequences of false alarms and their relationship to probability of detection are important in design and evaluation of animal systems.

The special capability which an animal has to carry out a critical function in the mission is important. On the other hand, that performance capability must be considered within the context of an overall system concept. A particular marine animal might have an acoustic signal detection capability. However, the limited diving and load carrying capacity of that animal might cause it to be rejected if the system called for delivery of a package to the signal emitter. An animal with a lesser acoustic capability, but possessing other required attributes, might be chosen. All facets of the animal's physical make-up and behavior which will be brought into play by a system must be considered during system concept formulation.

7.2.3.4 Life Cycle Costs are the aggregate of system development, acquisition, and annual operating costs over the expected life of the system. For some animal systems, special facilities may be needed to hold and maintain the animals (pen, cages, etc.). Unusual, in terms of previous Coast Guard needs, personnel specialities may be required. For example, veterinary services and personnel with special training in handling and training animals may be needed. To keep systems in the necessary degree of readiness, simulators and other training devices may have to be developed and provided along with operational systems hardware. Satisfaction of all those requirements must be included in the calculation of system life cycle costs.

8.0 POTENTIAL USES OF ANIMAL SYSTEMS BY THE COAST GUARD

8.1 INTRODUCTION

The main objective of this project was to determine in what ways animal systems could assist the Coast Guard in dealing with the problems it will face in the future. While there was no step by step procedure for creating system concepts, the process was not haphazard.

All of the information gathering and analyses reported earlier provided the basis for ideas on how animals could be employed. An understanding was obtained of projected Coast Guard missions and problems in the developing marine environment. At the same time, the literature on the capabilities of various types of animals was studied. Previous and current uses of animals by man were reviewed.

With all of that information in mind, each Coast Guard mission was considered. Project participants evaluated

- How each mission could be performed with the use of animals
- Which animals could be used
- How they might be employed.

Initially, the thrust was to get as many ideas expressed as possible even though some might be outlandish. However, during that process, thought of the criteria and constraints on use of animals discussed earlier in this report (Section 7.0) kept the concepts from becoming absurd. Also, to insure that no good prospects were being missed, attention was focused on the special qualities of particular groups of animals. An effort was made to find ways of using unique capabilities. Finally, the selection criteria were more deliberately applied to filtering concepts.

It is possible that some promising utilizations of animals were missed. However, the resulting set of concepts does cover a broad range of Coast Guard missions. Some of the missions are currently being performed. Others can be anticipated. Most of the concepts utilize trained, captive animals. The concepts vary considerably in terms of the portion of the mission which the animals would perform. They also differ with respect to development risk, the likelihood that the system can be built to operate as desired. For some applications, the Coast Guard might build and operate the systems. In other cases the Coast Guard might develop and evaluate the system and then specify its use by others, e.g., industry or shipping firms.

Several concepts are described below in the order in which the missions were previously defined (in Section 3.1). All of the missions are treated. There is no prioritization of systems here. Where no system concept is offered, that fact is so stated. It should be noted that some system concepts could be implemented in various ways. A few variations of some concepts are described. During system development, there still would be many design options to consider and trade-offs to be made.

8.2 TRAFFIC FLOW FACILITATION AND CONTROL

8.2.1 Traffic Control

No system concept is offered. The complexity of the tasks, their decision-making nature, and the requirements for verbal communications preclude utilization of animals for the tasks anticipated in this mission.

8.2.2 Aiding Navigation

Many animals have amazing navigation systems for their migrations or finding their way home. Some of the techniques they use, e.g., celestial navigation, are also used by man. No concepts were offered for using animals to aid in navigating ships. Electronic aids should be able to satisfy future requirements.

8.2.3 Ice Operations

Birds could be used to fly from icebreakers to find leads or thin areas in the ice. The system could supplement the use of helicopters for that task and provide a reconnaissance capability to icebreaking ships without helicopters. The system would operate as follows.

A small electronic package would be attached to a trained bird, possibly a pigeon, on board the icebreaker. The bird would be released to fly out in the direction in which the icebreaker wished to proceed. Guidance signals could be transmitted to the bird by radio via the electronics package. However, flying at several hundred feet in altitude ahead of the icebreaker should give the bird sufficient field of view to pick a good path.

The bird would be trained to detect openings in the ice or thin areas by their different coloration. It would go over those areas and perform a trained maneuver (such as circling or dipping in altitude). Performance of the maneuver would trigger the transmission of a signal to the ship. When the signal is received, the range and bearing would be marked on a display. Position of the bird could be obtained from a radar transponder in the electronics package carried by the bird.

After each thin ice position is received, the bird could be commanded to fly further out or in a different direction for a short period before indicating another location. In this way a plot could be generated of thin ice locations and a good path selected by the icebreaker's captain.

8.3 SAFETY AND EMERGENCY OPERATIONS

8.3.1 Safety Inspections

8.3.1.1 Hull Inspections (Exterior). The Coast Guard conducts a biannual safety inspection of all U.S. flag vessels. This includes examination of the exterior of the hull. Often the inspection is performed while the ship is in dry dock, but sometimes it is done in the water. Commercial divers with TV cameras are used to get pictures for the Coast Guard inspectors.

An alternative would be to train a sea lion to carry a TV camera around the ship. The Cc· c Guard inspector would transmit signals to guide the animal over the various parts of the hull to be inspected. An acoustic transponder and display would give the inspector information on the location of the animal. A fiber optic link could be employed to transmit the TV picture and to send the sea lion guidance signals.

This system does not provide any new capability or solve any major problems. However, it may be more economical, thorough, or faster.

8.3.1.2 Interior Inspections. There are narrow, difficult to reach interior spaces (e.g., between outer and inner hulls) which are inspected. There are also interiors of tanks in which inspectors occasionally are overcome by fumes or lack of oxygen. It is possible that an animal could be guided through those areas while carrying a TV camera. The inspector, located in a safe place, would view the pictures and send guidance signals to the animal. The animal, rather than a human, would be exposed to the risks. Dogs, cats, monkeys or other small primates might be considered for such an application.

8.3.2 Surface Search and Rescue

8.3.2.1 From Boats. Many search and rescue missions are conducted by helicopters or fixed wing aircraft. The Coast Guard will have the Sea Hunt animal system to support those operations. However, searches are also conducted from surface vessels. An animal system could be developed to give Coast Guard boats a bigger field of view thereby improving the efficiency of searches. Three concepts are suggested.

A pigeon or visually superior bird such as a hawk could be trained to fly up and circle several hundred feet over the Coast Guard boat. The animal would look for the orange distress panels, life vests, or rafts. When the bird detects such an object, it would fly in that direction until recalled by a radio signal. The Coast Guard boat would drive in the direction indicated by the bird. A radar transponder on the bird might be used to keep track of its location. Each boat could carry a few birds which could be rotated if the mission is long.

An alternative concept requires towing a parafoil from the search boat.* Birds would be in a lightweight module suspended below the parafoil and search for distressed vessels or personnel as the Sea Hunt system does. An added option is to include a TV camera on the module. When a bird detects a target, the camera could be slewed to the direction in which the bird is looking. Then the crew of the boat could verify that it was a distressed party which was detected by the animal.

Perhaps a small vial containing a pheromone or other potent odorant could be attached to life vests and rafts. When broken the odor would gradually be released and drift downwind. It could be detected by dogs or instrumented insects on boats searching for the victims.

8.3.2.2 Night Searches. A Sea Hunt type system or either of the bird systems proposed above (in 8.3.2.1) could be implemented utilizing owls instead of pigeons to give a night search capability. The owls would have to be trained to detect boats and people in the water rather than the international orange color which would not show up under low illumination levels. It is also suggested that the aircraft and helicopter crews be provided with night vision (light amplification) goggles to improve their search capability and follow-up of contacts by the animal search system.

8.3.2.3 Quick Inspection of Aerial Photographs. Occasionally, high altitude aerial photography searches are made. Thousands of frames of film are taken. It is suggested that pigeons be trained to rapidly review those frames to pick out the few which have in them objects of interest. Those frames selected could then be scrutinized by human observers.

8.3.2.4 Recovery of Man Overboard. A bird could be released from a ship from which a man had fallen or been swept overboard. The bird could be trained to search back over the path of the ship and drop a smoke/flare/dye marker on the person when he is sighted by the bird. The bird

*NOSC TN 407, At-Sea Exploratory Tests of the Elevated Tethered Platform (ETP) Concept by K.J. Powers, 1 May 1978, gives data on parafoil performance and discusses potential Navy and Coast Guard uses of parafoils.

selected should be a strong flier and have good night vision. The utility of this system in any given situation will depend greatly (as does any chance of recovering a man overboard) upon the time between when the man actually went overboard and when that event is discovered. A dog or sea lion could also be used to aid a man overboard.

8.3.3 Underwater Rescue

Underwater public and commercial parts should have their own rescue vehicles and equipment. Likewise, offshore industrial activities should be equipped to rescue their own stranded submersibles. The Coast Guard may issue safety and rescue requirements for undersea activities.

A system could be developed by the Coast Guard for underwater rescue of submersibles or of people trapped in undersea installations. The system would be similar in operation to the Navy's Quick Find. All submersibles and installations should be equipped with pingers so they can be located readily. They should also have specially marked attachment points for connecting rescue equipment.

When information is received that a submersible or habitat is in distress, a marine mammal (porpoise or sea lion) is transported to the area along with rescue equipment. Listening devices are used to get the rescue party near the stranded submersible. Then the animal is put or jumps into the water and verifies that it, too, hears the pinger.

The porpoise or sea lion is given a clamp to carry down to the distressed vehicle. A line attached to the clamp also is towed down. The animal connects the clamp to the marked padeye and returns to the surface. Then the line from the surface to the distressed vehicle/installation is used to:

- Raise the submersible by use of a crane
- Lower and connect gas generators and buoyancy bags
- Move a rescue chamber down and back up

The system should be highly mobile. It would have a depth capability between 600 and 1500 feet. If distressed vehicles are not equipped with pingers, an animal system could be designed to perform the search as well as aid the recovery function. A porpoise with echolocation capability could be employed.

8.3.4 Aiding Vessels/Structures in Distress

Occasionally there is difficulty in getting a line across from a rescue vessel to a distressed vessel/structure. A sea lion or possibly a dog could be trained to carry a messenger line from one to the other. The messenger line then can be used to pull across a tow or rescue line.

8.4 UNDERWATER INVESTIGATION AND RECOVERY

8.4.1 Sunken Vessel/Structure Inspection

When a vessel sinks or is scuttled (to conceal criminal activities) it is often desirable to study the sunken hull to determine the nature, extent, and possible causes of the incident. A marine mammal might be used to carry a TV camera down for an inspection.

The hull would be located initially with a hardware search sonar. Then the animal would be put overboard near the target to locate the vessel itself.

After the animal locates the target, it would tow a TV camera and lights to the sunken vessel. The equipment might be mounted on a sled. The picture would be transmitted back to the surface via a fiber optic link. The inspector on the surface views the picture and transmits guidance signals to the animal.

8.4.2 Body Search and Recovery

A porpoise, a ray, or possibly a turtle could be trained to search for and recover bodies.

8.4.3 Package/Equipment Recovery

A number of marine animals might be used to find and recover packages from the ocean floor. Of particular interest is the recovery of marijuana thrown overboard or from the inside of scuttled vessels. Some animals which should be considered for such a mission are those with good chemoreception. Fish like salmon, sharks, or rays are promising candidates. Additional data on a sea lion's chemoreception might qualify it for consideration. The animal would be deposited by a boat on the surface as close as possible over the known point of the dumping. The gradients of chemical concentration of marijuana components in the water would lead the animal to the packages. The animal would either bring back a sample of marijuana in its mouth or attach a recovery device to the package.

8.5 LAW ENFORCEMENT AND SECURITY

8.5.1 Smuggling Control

Currently, the Coast Guard's most challenging and resource-demanding role is the control of smuggling of marijuana and hard drugs. This mission is projected to continue in importance well into the future. Several system concepts were formulated to help the Coast Guard select which ships to intercept and, once boarded, to determine whether or not marijuana is onboard.

8.5.1.1 Suspect Ship Selection. Four different approaches were taken for utilizing the olfactory capabilities of animals to determine which ships are transporting marijuana. These involve different animals and different ways of obtaining the air samples for them to sniff.

In the first concept, birds selected for relatively good olfaction would be carried on Coast Guard cutters. When boats are sighted by the patrolling cutter, the bird is released and guided by radio transmitted commands towards one of the boats or the boat is illuminated by a laser on which the bird homes. The animal has been trained to circle low over the boat and land on it momentarily if the odor of marijuana is detected. The landing triggers a signal which is transmitted back to the Coast Guard cutter. Then the animal is signaled either to return to the cutter or directed toward another boat to inspect. A sea bird which may have the best olfactory capabilities for this job is the Northern Fulmar.

Another idea is to have an animal with excellent olfaction in an airborne vehicle (helicopter, fixed wing aircraft, remote-piloted vehicle or a blimp). The vehicle flies over each boat to be checked out and sucks in samples of air just down wind of the boats. The samples are presented to a dog, gerbil, or pig which indicates whether or not the odor of marijuana is present. The advantages of this concept include greater quantities of air which can be tested and the opportunity of using the animal with the most olfactory sensitivity.

To check out boats coming into harbors, an animal could be stationed appropriately (down wind) of the narrow point at the harbor entrance. The animal would give a conditioned response whenever it detected a boat going by with a load of marijuana. The animal station might be alongside the channel, on a bridge over the entrance, in a balloon over the entrance, or on a Coast Guard boat sitting in the channel. Rodents, dogs, or pigs are potential sensors.

It may be possible to breed an insect, such as a fruit fly, with an excellent olfactory sensitivity for marijuana or other narcotics. Bioluminescence bacteria also could be considered. That sensitivity may be found to occur naturally in a few of the animals if a great number are tested. If not, it may be found after use of a mutagen to produce more variations in the population bred in the laboratory. If the desired sensitivity is found, then a behavior, such as increased activity level in the presence of the stimulus scent, must be identified and instrumented. The insects could be used to test air samples obtained in any of the ways described above. A small container of insects could even be carried by a bird to a ship and back.

8.5.1.2 Suspect Ship Inspection. When a ship is suspected of smuggling and is boarded by Coast Guard personnel, an animal system may be useful for verifying the presence of and locating the smuggled goods. Detection of marijuana and perhaps other drugs or firearms would be possible. Of course, a dog trained for narcotics detection could board the ship with Coast Guard personnel. Alternatively, a small animal such as a gerbil or rat could be carried in an attache case size package with appropriate instrumentation. The animal would either press a lever when it detected marijuana or be instrumented so that the brain wave response to marijuana could be recognized. In either case, the presence of marijuana or other drugs would be indicated to Coast Guard personnel by a light on the attache case. Another possibility is genetic development of strains of insects or bacteria which are sensitive to the vapors given off by marijuana. The insects would respond with high activity level and the bacteria by bioluminescence.

An indication of the presence of marijuana might come as soon as the ship or boat is boarded. The system might be used to locate the goods on the ship. Levels of brain wave activity, the jumping of insects, or bioluminescence are proportional to odor concentration. The gradient of response might be tracked to the source.

On ships with containerized cargoes, provisions for sampling the air from the containers would enable the Coast Guard to check for marijuana. Any of the approaches described in this section could be tried. Inspection of containers could be conducted on shore before the ship is loaded or after unloading.

Although the odors are not as intense, other narcotics, explosives, or firearms might be searched for by similar systems.

8.5.2 Theft Control

8.5.2.1 Waterfront Facilities. Several types of animal systems can be used to guard waterfront facilities to prevent theft of materials. The systems would be designed to detect movement of personnel where no one is supposed to be. Guard dogs, of course, can be employed. Historically, geese have also been used as an intrusion detection systems. Another concept is to train pigeons (for daylight) or owls (for day or nighttime) for guard duty. The animals would be in special boxes with viewing windows located to provide a good view of the controlled areas. The animals are trained to peck on a key in the box whenever they see a person. The key pecking response could set off a loud alarm or send out a call for security forces.

8.5.2.2 Aquacultures. When open ocean aquaculture develops, there may be a need for a system to guard against poaching.

An idea is to condition the fish being grown in the aquaculture to signal the approach of a boat. For example, the fish might be fed frequently at a specific location whenever a boat approaches. Then when a poacher comes to the facility, the fish would congregate in the feeding area.

An electronic device would detect the intense activity there and alert the security forces.

8.5.3 Terrorism Control

8.5.3.1 Bird System for Facilities and Ship Security. Trained birds are put in observation modules which have a good view of waterborne approaches to such assets as:

- Oil rigs
- Offshore power plants
- Moored ships
- Waterfront facilities

The birds could also observe fencelines along controlled access land facilities. Whenever a bird detects a man or boat approaching the asset, it pecks a key which triggers an alert to security forces. The system might be set up so that the bird pecks its viewing window at the place it detects the intruder. A transducer embedded in the window would pick up and relay the direction of intruder approach.

The birds would have to be trained to report swimmers on the surface of the water, small boats, people climbing up the side of an offshore facility, ship, or fence, or penetrating a fence. Because of their superior night vision, owls are suggested for employment in this system. Pigeons with their wide field of view would be good for daytime use if required.

8.5.3.2 Defense Against Swimmers Attacking Offshore Assets. Fish and other marine life tend to gather and inhabit the areas around oil rigs. The rigs act as artificial reefs. The fish at those sites might be conditioned to collect at specific locations everytime a swimmer is in the water near the oil rig. This might be accomplished by associating the presence of a swimmer with the delivery of food. A swimmer or scuba diver frequently would be put in the water near the rig and swim towards it. Food would be released at a specific location on the rig. After a conditioning period, the fish should gather at the feeding station whenever a swimmer/diver is in the area. The congregation of fish at the station can be detected by a small sonar transducer or an optical system. An alert would be given to security forces on the rig.

8.5.3.3 Cruise Ship Passenger and Baggage Inspection. Cruise ships could be subject to takeover by terrorists boarding as passengers in much the same way as aircraft hijackings have taken place. It may become desirable to inspect passengers and their luggage for firearms and explosives. A few system concepts are proposed.

Dogs could be used to inspect passengers while not interfering with their civil liberties or putting them in a stressful situation. The approach, described previously, used by researchers at the Allied-General Nuclear Services research and development facility in Barnwell, South Carolina is suggested. Each passenger would step into a booth. Air blown down from the top to the bottom of the booth would exit a port at the bottom where it would be sniffed by a dog trained for explosives detection. Upon detecting explosives, the animal would give a sit response. A pig would also be a good candidate animal. Rodents or insects in instrumented boxes could be employed. All of these animals could be completely concealed from the passengers. This system might supplement use of metal detectors for firearms.

Dogs could also be used in a separate area to sniff luggage to detect explosives. This is the same system the FAA uses to inspect aircraft

luggage when a bomb threat is received. It should be remembered that an important difference between aircraft and cruise ships is that on cruise ships, the passengers have access to all of their luggage.

Another idea, the feasibility of which needs to be demonstrated, involves X-raying luggage. Instead of just having a human operator examine the screen, a trained pigeon is also employed to pick out items which show patterns indicative of explosive devices or firearms. For example, the combination of images presented by wires, sticks, or blocks of explosives, timing mechanisms, and detonators, may be recognizable by a pigeon. Hand grenades and guns also may be detected. The FAA has expressed interest in this concept.

8.5.4 Control of Fishing

There are a few ways in which animals could be used to detect and signal when fishing is being carried out in a controlled area. One is to have birds in balloons tethered above controlled fishing areas. The birds are trained to peck a response key whenever boats fish in the area. The response would be transmitted by radio to the Coast Guard. The animals would have to be taught to discriminate between boats involved in fishing and those just transitting the area. A boat authorized to fish would have an electronic identification device. A radio signal from the device would block transmission of the alert signal from the balloon or be retransmitted to the Coast Guard for identification of the boat.

Alternatively, a sea bird could be trained to fly freely between widely separated buoys and report fishing activities detected. Detections might be signaled by a response given when the bird reports in at a buoy or by a radio transmission from the bird when it lands on the water upon detecting a fishing boat.

8.6 ENVIRONMENTAL PROTECTION

8.6.1 Monitoring and Surveillance

A system which uses bioluminescent bacteria to test water quality was described earlier (Section 6.7.2). It may also be possible to grow

strains of bacteria sensitive to specific pollutants. Such systems would provide the Coast Guard with sensitive and discriminating field assay kits for detecting and tracking pollution in various areas under Coast Guard congnizance.

Also, it is possible that small fish, such as minnows, could be trained to indicate the presence of specific chemicals in the water.

8.6.2 Well Head Inspection

The Coast Guard may get involved in the inspection of oil rigs and production sites to prevent pollution. An animal system might be helpful in performing visual underwater inspections of well heads. A large sea lion, dolphin, or ray could be trained to maneuver a TV camera and lights around the well head. A fiber optic cable could carry the image to an inspector on the surface or the picture could be put on video tape (to avoid cable entanglement). This system would be similar to the one suggested for ship hull inspections except the depths would be greater, but the inspection area smaller.

8.6.3 Investigation

No ideas are offered for use of animals to aid in pollution incidents investigations.

8.7 MILITARY OPERATIONS

8.7.1 Protection of Offshore Assets

System concepts for detecting small boats or swimmers approaching offshore assets during wartime are the same as those suggested to control terrorist activities. During wartime, the threat and need to protect more facilities may be greater.

8.7.2 Protection Against Landings

Secluded beaches could be patrolled by animals to alert defense to the landing of small enemy units or agents. Of course, dogs and their handlers could patrol beaches. Sea lions also could guard beaches. Birds (owls at night) could be trained to fly between stations separated by several hundred yards along the beach. At each station the animal would report whether or not it spotted people along its flight path.

8.7.3 Ocean Surveillance

No system concepts are offered for ocean surveillance.

8.7.4 Explosives Loading/Unloading Supervision

No system concepts are offered to perform this mission. However, maintaining security of the area might be supported by systems described above (8.7.2).

8.7.5 Natural Disaster and Domestic Emergency Operations

A system for underwater body search and recovery was described previously (Section 8.4.2). That system might be useful when trying to determine the number of and recover casualties of major disasters. There will also be casualties on land or the water surface. People may be buried under rubble or mud or floating on debris. Birds and dogs could be used to find the injured as well as the fatalities.

The British and Israelis have systems which use dogs with their handlers to search for bodies on land. The Coast Guard could develop a similar system. The system could be designated to find injured personnel buried under or hidden in the rubble of buildings.

Pigeons or birds of prey could be trained to circle over ravaged areas and visually detect casualties. It should be possible to train the bird to even pick out a limb protruding from under debris. When a casuality is detected, the animal would land next to it. The landing would trigger a homing device to allow rescue workers to find the casualty.

8.8 SUPPORT

8.8.1 Communications

No animal systems are suggested for supporting the communications mission.

8.8.2 Intelligence and Security

Coast Guard facilities can be protected from intruders by animal security systems described previously (Section 8.5.2.1).

No regular role in intelligence operations is proposed for animals. Detection and identification of odorant tags covertly placed on ships or contraband by agents is an exotic concept that might occasionally be useful.

8.8.3 Maintenance

No suggestions are offered for use of animals in maintaining Coast Guard boats or facilities.

8.8.4 Science Support

Scientific missions will vary greatly in their objectives and conduct. No regular use is foreseen of animal systems by the Coast Guard in support of those missions. One can conceive of the use of marine mammals to track other marine mannals, find fish concentrations, or collect water or bottom samples at different depths.

8.8.5 Public Relations

One or more animals could be used by the Coast Guard as a symbol to create goodwill and help relay Coast Guard messages to the public. Smokey the Bear has served the U.S. Forest Service very well for those purposes. The Coast Guard could use a sea lion or porpoise. If the Sea Hunt system is well publicized, a pigeon could be used to support boating safety campaigns.

In addition to appearances on posters and other printed information, some animals could be trained for television shows, for entertainment and publicity at boating shows, and even to travel around for appearances at marinas and Coast Guard auxillary meetings. For those purposes, logistics and mobility would suggest use of a sea lion or perhaps an otter as a marine mammal symbol rather than a porpoise.

8.8.6 International Relations

If the Coast Guard is successful in employment of animals for some of its missions, transfer of that technology to some other countries could serve to aid international relations.

8.9 DISCUSSION ABOUT SUGGESTED CONCEPTS

The system concepts suggested above cover a broad spectrum of the Coast Guard's missions. The concepts vary greatly in potential cost-effectiveness and in risk undertaken in their development. These criteria as well as the others presented early in this report (Section 7.2) considered when program planning recommendations are presented. For several system concepts, the development risks are low since identical or similar systems have been developed and are being used by other agencies. Included in that category are the use of dogs for narcotics and explosives detection, and marine mammals for underwater search and object recovery tasks, e.g., Quick Find and Deep Ops mentioned earlier. Concepts with higher risk and corresponding need for more research include use of free flying guided birds, fish, insects, and bacteria. With respect to cost-effectiveness, it should be noted that most of the systems are single purpose. While the same bird may be used to guard an oil rig, a ship, or waterfront facility, that animal cannot also be used for narcotics detection.

The animals and their associated special sensory capabilities proposed for use in the various system concepets are:

Animal	Sense
• Bacteria	Chemoreception
• Insects	Olfaction
• Fish (including sharks and rays)	Olfaction, vibration, electromagnetism
• Rodents	Olfaction
• Birds	Vision (day and night), possibly olfaction
• Dogs	Olfaction
• Pigs	Olfaction
• Marine mammals	Audition and echolocation

The potential use of the sense of smell is noteworthy. It is a sense which is highly developed and used by many animals but not so much by man. Therefore, the animals contribute something unique. Likewise, echolocation by porpoises provides a special search capability. While man makes good use of vision, some birds are superior. Owls have far better night vision, hawks and eagles have greater acuity, and pigeons have the same acuity as man but over a wider field of view. Birds are also more attentive than man to search tasks over prolonged periods.

In addition to the special sensory capabilities of the animals, other qualities were utilized. The small size of bacteria, insects, rodents, and birds makes them easily transportable. They can also be bred rapidly. The diving and mobility of marine mammals and fish was exploited as was flight of birds.

Most of the concepts proposed involve performance of one of the following tasks:

- Guard duty (detection of intruders)
- Inspection tasks (carrying instrumentation)
- Searching for and recovering something on the water surface or sea floor
- Detection of hidden materials (e.g., narcotics)

The systems generally use trained captive animals, although some are only under behavioral, not physical, control during performance of the mission. A few of the concepts involve conditioning animals in the wild and subsequently observing them to determine when the conditioned stimulus (e.g., the approach of an intruder) has occurred. Also, a few ideas were presented for breeding animals (insects and bacteria) to respond to selected stimuli (e.g., pollutants) and using them to detect those stimuli. No bionics systems were proposed. Research breakthroughs in understanding marine mammal echolocation or animal olfaction processes could pave the way to hardware implementation of several of the animal systems proposed. Likewise, better comprehension of electromagnetic sensing could lead to better metal and proximity detectors.

9.0 POTENTIAL USES OF ANIMALS BY OTHER ORGANIZATIONS

In addition to conceptualizing uses of animals by the Coast Guard, thought was given to future uses of animals by other organizations which interact with the Coast Guard. Those groups may be law enforcing, law abiding or law breaking. Possible uses are discussed below along with their impacts on the Coast Guard.

9.1 OTHER GOVERNMENT AGENCIES

9.1.1 Continued Use of Dogs

Because of their capabilities and the ability to use them in various working environments, it is likely that dogs will continue to be used by several federal agencies. Detection of explosives and narcotics and sentry and patrol duties will be their tasks. Not until electronic devices are developed which are both as sensitive as the canine, are compact, and easy to utilize, will the employment of dogs be discontinued for detection tasks. Not much innovation is expected in the use of dogs; dogs and handler will continue to work together as a close knit team.

9.1.2 Research on Rodents

Within a few years there should be sufficient research results to determine how useful rodents (mainly rats and gerbils) will be for detection tasks. The Army, Federal Aviation Administration, and Bureau of Alcohol, Drugs and Firearms are sponsoring research to determing the olfactory sensitivity of those animals to materials of interest and the best way to get the information from the animals. If those results are positive, then operational systems utilizing those animals could be seen within five years. The main advantages of the rodents as compared with dogs will be compactness of the system (therefore greater mobility), unobtrusiveness, lower cost, and more standardized training. Again, breakthroughs in development of hardware systems would probably draw interest away from rodent applications.

9.1.3 Systems Employing Birds

The Coast Guard's Sea Hunt system may stimulate interest in the use of birds for other applications by other government agencies. At least two other feasibility studies are being considered by two different agencies.

9.1.4 Marine Mammals

Research and systems development work by the Navy is expected to continue. Within the time frame of interest, more systems should become operational. Some of these will be hybrid systems involving cooperative, interactive use of hardware with the animals. Development of a bionic sonar incorporating many features of porpoise echolocation will be realized.

9.2 INDUSTRY

There are no indications of any surge in interest by industry in innovative uses of animals. Use of dogs for guard duty could increase as the overall security industry grows. However, there may be increasing competition from electronic intrusion detection systems. The popularity of animals in the entertainment field, including commercial parks, and for promotional purposes should continue.

The impetus for growth of employment of animals by industry could come from government research and development and imposed requirements. After the flurry of aircraft hijackings a few years ago, the airlines were required to provide systems for inspecting passengers and luggage. Similarly, if an animal system proves valuable in a public safety role, its use by industry could be stimulated or even required.

9.3 ANTISOCIAL FORCES

There is no reason to expect that terrorists or criminals will make use of animals to achieve their goals. At least for the foreseeable future

those groups can continue to employ other, more economical approaches. Because of their success with current methods, they do not need to spend the time and resources required to develop and maintain animal systems.

9.4 IMPACTS ON THE COAST GUARD

The animal work by others will have little direct impact on the Coast Guard. The limited work being conducted by other agencies will provide the Coast Guard with considerable technology for developing its own systems or adapting, for Coast Guard use, systems developed by others. Opportunities will be available for utilizing the expertise and resources of other agencies or participating in joint R and D efforts. An example is the development of a dog system. The Military Working Dog Center at Lackland Air Force Base could be recruited to support the Coast Guard in that endeavor. Likewise, research on chemoreception applications of insects could be supported jointly by the Coast Guard and Customs.

10.0 RECOMMENDED PROGRAM

Many possibilities have been suggested for use of animals in performance of Coast Guard missions. Some systems may even be adaptable for multi-mission performance. The system concepts vary greatly in feasibility, utility, and cost of implementing. Certainly, the Coast Guard will want to be highly selective in the animal system developments it wishes to undertake. This section deals with the selection of system concepts for further consideration by the Coast Guard and the means by which those chosen may be realized. First, the status of technology in using various types of animals is summarized. Then there is a discussion of different ways the Coast Guard can get involved in system development. Finally, system concepts are evaluated and recommendations are made for specific projects.

10.1 TECHNOLOGY STATUS

Several types of animals are employed in various ways in the system concepts suggested. The status of technology in obtaining, keeping and using different animals in large part will determine the nature and success of each system development venture.

10.1.1 Dogs

Of the animals suggested, man has the most experience working with dogs. The systems which use dog-handler teams should be the easiest to get operating as conceived. The animals are used for detection of drugs, explosives, and, in security roles, people. Whether or not the animals have the sensory sensitivity required for acceptable performance in a specific application is open to question and should be verified experimentally.

10.1.2 Birds

The technology for keeping and training several kinds of birds also is quite advanced. There is considerable expertise in working with pigeons and some birds of prey. Tasks in which pigeons in a chamber report on their

visual observations or birds of prey fly overhead and dive on targets should not be difficult to demonstrate. Project Sea Hunt has already shown the utility of pigeons for one Coast Guard mission. Concepts which required fitting electronic packages on birds and guiding them in flight are riskier. Not only will the behavior control technology require advancement, but development of the very compact, lightweight electronics will be challenging. Training birds to fly out searching with no identified termination point to the flight (e.g., in the ice breaking operations system concept) could prove difficult. For several of the concepts proposed, additional work, literature research, analysis, and experiments should be conducted to select the best species for the mission.

10.1.3 Marine Mammals

The acquisition, husbandry, and training of marine mammals is much more recent than use of dogs or birds. However, great advances have been made in those technologies. Several species have been captured, maintained healthy for years, trained, and even bred. Long range transport and delivery to working sites has been perfected.

Marine mammals have been trained to perform detection tasks in their pens, or as in the case of Quick Find and Deep Ops, in the open ocean. Systems in which the animals remain unattended for long periods of time present greater problems of animal control and task behavior maintenance.

10.1.4 Insects

A few suggestions have been made for use of insects. The animals are not trained. Instead, their natural responses to innate or selectively bred sensitivities are employed. This approach presents several problems.

First is the problem of finding and developing, by selective breeding, a population of insects which are sensitive to the stimulus of interest, e.g., the odor of marijuana. Then that population must be maintained. Finally, the response of the insects to the stimulus must be observed and instrumented so that the response information can be passed on to system operators. While these problems may not be insurmountable, they pose many research questions which must be answered before system feasibility can be demonstrated.

10.1.5 Fish

The behavior conditioning and electronics technologies utilized with other animals will certainly be applicable to development of systems employing fish. However, little is known about the complexity of the tasks which fish (including sharks and rays) can be trained to perform. Work in that area is in its infancy. Likewise, the sensitivity of fish to specific stimuli which they need to detect (e.g., selected pollutants) is not known. Therefore, before fish can be utilized in systems to support Coast Guard missions, several research questions will have to be answered and innovative use made of current technologies.

10.1.6 Bacteria

Use of bacteria was suggested only for a few missions. The most promising of these is use of bioluminescent bacteria to detect pollutants in water. As described earlier, a commercial system is already on the market to evaluate overall water quality. However, research will be required to determine the feasibility of using bacteria to detect and identify specific pollutants. Considerable technology exists for conducting that research and for culturing bacteria once the appropriate strain is isolated.

10.1.7 Bionics

Advances in bionics will depend upon behavioral, physiological, and anatomical research on the animals possessing outstanding capabilities.

Support is needed for research on marine mammal echolocation and olfaction in several animals. The signal processing which the animals perform must be as well understood as the sensory mechanisms to produce a complete bionics system. However, hybrid systems in which the human does the processing of signals from a bionics sensor are also possible. For example, it has been shown that humans can use returns from artificially generated porpoise echolocation pulses to perform target discrimination tasks.

10.1.8 Primates

Monkeys and apes are not recommended in this report for utilization in systems. A combination of two reasons led to their exclusion. For the most part, these animals generally do not exhibit sensory capabilities which are very exceptional relative to man. Second, they require considerable care and attention, including a great deal of social interaction. To utilize a primate effectively might require a full time trainer/handler.

10.2 OPTIONS FOR COAST GUARD INVOLVEMENT

There are several levels of potential Coast Guard involvement in development and use of animal systems. Of course, the Coast Guard may choose to undertake complete development and sole utilization of a system. For some of the systems proposed, that may not be either necessary or wise. At the other end of the spectrum, the Coast Guard may simply monitor the research and development work of other organizations and be alert to possibilities for greater involvement at an opportune time.

In between those two extremes are several other levels of Coast Guard participation. Other agencies have similar interest to the Coast Guard and are employing or investigating animal systems. As examples, Customs is involved in stopping smuggling of narcotics. The FAA and Secret Service, among others, are concerned with detecting explosives. The Coast Guard could cosponsor animal systems research and development work with those agencies. If another

agency develops a system similar to what the Coast Guard needs, the Coast Guard might arrange to buy units of the system from that agency or contract for procurement of the same or similar design. Modifications may have to be made for Coast Guard applications. The Coast Guard may not want to make the investment in animal training facilities and personnel which duplicates those of other agencies. Trained dogs could be obtained from the Air Force, and marine mammal training can be accomplished by the Navy.

If the Coast Guard does develop a system, it may choose to not operate the system itself. System use may be recommended to or even required of industry.

10.3 SUGGESTED PROJECTS

10.3.1 Selection Approach

There were almost fifty system concepts suggested in Section 8.0. For some missions, several concepts or variations of a concept were proposed. Of course, the Coast Guard might only have the resources to support just a few of the worthiest proposals. To provide a basis for selecting projects to recommend, each of the system concepts was evaluated against seven of the higher level criteria presented early in this report (see Section 7.0). An additional criteria, "immediacy," was added for this project selection purpose. That criteria concerns how pressing the demand is for a system to perform this mission. Some missions are currently being performed, and better systems are needed. Others may not be required for some time.

Each concept was evaluated in terms of the criteria using a five point scale. A five represented the most favorable score and a one, the poorest score. In other words, a five on the Alternatives criteria means that there are no hardware/personnel systems capable of performing the missions; a one implies there are lots of better ways other than use of animals. Three judges participated in this evaluation. One is the lead author of this report, the second is the contractor from Integrated

Sciences Corporation, and the third is manager of another animal R&D project at NOSC. The ratings of the three judges on each criteria were averaged. The criteria were equally weighted and the scores of each were simply added to obtain a general, overall appraisal of each system concepts (see Table 2).

For each of the high scoring concepts within each group of missions, thought was given to the status of the technology with respect to utilization of the type of animal suggested (see 10.1 above). The most appropriate option for Coast Guard involvement in system development also was considered. Then the recommendations were prepared.

The importance of additional mission and system analysis and more detailed concept definitions as a first step in undertaking any of the proposed projects is emphasized.

10.3.2 Sea Hunt

The Sea Hunt system was excluded from the evaluation because it is already well into development for the Coast Guard. Sea Hunt is becoming the state-of-the-art for daylight over-the-water search missions. The technical feasibility has been demonstrated. Introduction of the system to Coast Guard operational units is recommended.

10.3.3 Bird Deployed From Boat for Surface Search

This system (see 8.2.3.1) employs a bird circling over a Coast Guard boat to find people in life vests or rafts, or in disabled boats. After more analyses are conducted of search and rescue missions from Coast Guard boats, further study should be given to the selection of species of birds to utilize for this system. The literature should be examined further and bird trainers and curators consulted. There is more experience in the training of soaring, predatory land birds with the required visual capabilities, but a sea bird might be more appropriate.

Table 2 : Evaluation of System Concepts

REPORT SECTION	MISSION/CONCEPT	ACCEPTABILITY	DEVELOPMENT RISK	PRODUCIBILITY	ALTERNATIVES	COST-EFFECTIVENESS	IMPORTANCE	LIKELIHOOD/FREQUENCY	IMMEDIACY	TOTAL
8.2	TRAFFIC FLOW FACILITATION AND CONTROL									
8.2.1	Traffic Control	—	—	—	—	—	—	—	—	—
8.2.2	Aiding Navigation	—	—	—	—	—	—	—	—	—
8.2.3	Ice Operations	3.7	2.0	3.3	2.3	3.3	1.7	2.3	2.3	21.9
8.3	SAFETY AND EMERGENCY OPERATIONS									
8.3.1	Safety Inspections									
8.3.1.1	Hull Inspections (Exterior)	3.7	4.0	3.7	2.3	3.0	2.0	4.3	4.3	27.3
8.2.1.2	Interior Inspections	3.3	1.7	3.3	3.3	2.7	3.3	4.0	4.3	25.9
8.3.2	Surface Search and Rescue									
8.3.2.1	From Boats									
	Circling Bird	4.3	3.3	3.7	3.0	4.0	3.7	4.0	4.0	30.0
	Bird on parafoil	3.7	3.0	3.3	3.3	2.7	3.0	3.3	3.7	26.0
	Odorant release and detection	2.3	1.3	2.3	2.7	3.0	2.7	3.3	3.3	20.9
8.3.2.2	Night Searches	4.7	3.3	3.7	3.0	3.3	3.7	3.7	4.7	30.1
8.3.2.3	Quick Inspection of Aerial Photographs	3.3	4.0	4.7	3.0	3.7	2.7	2.3	4.0	27.7
8.3.2.4	Recovery of Man Overboard	3.7	2.7	3.3	3.3	2.3	2.0	2.0	4.0	23.3
8.3.3	Underwater Rescue	4.7	4.7	4.3	3.0	3.7	2.0	2.3	3.0	27.7
8.3.4	Aiding Vessels/Structures in Distress	3.3	2.3	3.3	1.7	2.0	1.7	1.7	3.7	19.7
8.4	UNDERWATER INVESTIGATION AND RECOVERY									
8.4.1	Sunken Vessel/Structure Inspection	3.7	3.7	3.3	3.0	3.0	2.0	2.0	3.7	24.4
8.4.2	Body Search and Recovery	3.7	3.0	2.7	3.0	2.3	2.3	2.0	3.3	22.3
8.4.3	Package/Equipment Recovery	3.7	2.0	2.7	3.3	2.7	2.7	2.3	4.0	23.4
8.5	LAW ENFORCEMENT AND SECURITY									
8.5.1	Smuggling Control									
8.5.1.1	Suspect Ship Selection									
	Bird with good olfaction	3.0	1.7	2.3	1.7	2.3	3.0	4.3	4.0	22.3
	Animal sniffs air samples brought by bird	2.7	1.0	1.7	1.3	1.7	3.0	3.3	4.0	18.7
	Animal in airborne vehicle	3.7	3.3	3.7	2.7	3.3	3.3	3.7	4.0	27.7
	Animal at harbor entrance	3.7	3.0	3.3	2.7	3.3	3.3	2.7	4.0	27.0
	Insects or bacteria	3.0	1.3	1.7	1.3	3.0	3.0	3.3	3.7	20.3

REPORT SECTION	MISSION/CONCEPT	ACCEPTABILITY	DEVELOPMENT RISK	PRODUCIBILITY	ALTERNATIVES	COST-EFFECTIVENESS	IMPORTANCE	LIKELIHOOD/FREQUENCY	IMMEDIACY	TOTAL
8.5.1.2	Suspect Ship Inspection	4.0	3.3	3.3	3.0	3.3	3.3	4.0	4.3	28.5
8.5.2	Theft Control									
8.5.2.1	Waterfront Facilities									
	Guard dogs	4.7	5.0	4.3	3.3	3.3	3.0	3.0	3.3	29.9
	Birds	4.0	4.0	4.3	3.3	4.0	3.0	3.3	3.7	29.6
8.5.2.2	Aquacultures									
	Porpoises or sea lions	3.0	3.0	3.0	3.0	2.7	2.0	1.3	1.0	19.0
	Aquaculture fish	3.0	2.0	2.3	2.7	2.7	2.0	1.7	1.0	17.4
8.5.3	Terrorism Control									
8.5.3.1	Bird System for Facilities & Ship Security	4.0	4.0	4.0	3.3	4.0	3.7	3.0	3.3	29.3
8.5.3.2	Defense Against Swimmers Attacking Off-shore Assets	3.3	2.0	3.0	3.3	3.0	3.3	2.7	2.7	23.3
8.5.3.3	Cruise Ship Passenger and Luggage Inspection									
	Dogs	5.0	4.0	4.0	3.0	3.3	3.3	3.0	3.3	28.9
	Pigeons Viewing x-rays	4.3	3.3	3.7	3.0	4.0	3.0	2.7	3.3	27.3
8.5.4	Control of Fishing									
	Birds in balloons	3.0	2.3	2.7	2.3	2.3	1.7	2.7	2.7	19.7
	Free flying patrol birds	3.0	1.7	1.7	2.3	2.7	1.7	2.7	2.7	18.5
8.6	ENVIRONMENTAL PROTECTION									
8.6.1	Monitoring and Surveillance									
	Bacteria	4.3	2.0	3.3	2.3	3.7	3.0	3.0	3.0	24.6
	Fish	3.3	1.7	2.0	2.3	3.7	2.3	2.3	2.3	19.9
8.6.2	Well Head Inspection	3.3	3.3	3.0	3.0	3.0	2.7	3.0	2.3	23.6
8.6.3	Investigation	—	—	—	—	—	—	—	—	—
8.7	MILITARY OPERATIONS									
8.7.1	Protection of Offshore Assets	4.0	4.0	4.0	3.7	3.0	3.3	3.0	3.0	27.3
8.7.2	Protection Against Landings									
	Dogs or Sea Lions	4.7	4.7	4.7	3.0	3.3	2.0	2.0	2.0	26.4
	Birds	3.7	3.0	3.3	2.3	3.0	2.0	2.0	2.0	21.3
8.7.3	Ocean Surveillance	—	—	—	—	—	—	—	—	—

REPORT SECTION	MISSION/CONCEPT	ACCEPTABILITY	DEVELOPMENT RISK	PRODUCIBILITY	ALTERNATIVES	COST-EFFECTIVENESS	IMPORTANCE	LIKELIHOOD/FREQUENCY	IMMEDIACY	TOTAL
8.7.4	Explosives Loading/Unloading Supervision									
8.7.5	Natural Disaster and Domestic Emergency Operations									
	Dogs	4.7	4.7	4.0	3.3	3.3	2.0	2.0	2.0	26.0
	Birds	4.7	3.7	3.3	3.0	3.7	2.3	2.0	2.0	24.7
8.8	SUPPORT									
8.8.1	Communications									
8.8.2	Intelligence and Security									
8.8.3	Maintenance									
8.8.4	Science Support									
8.8.5	Public Relations	5.0	4.7	4.7	3.0	4.0	4.0	4.7	3.7	33.8
8.8.6	International Relations									

An experimental model of the system could be developed by the Naval Ocean Systems Center or a private contractor for evaluation by the Coast Guard. About a year and a half should be devoted to developing such a model and demonstrating feasibility and worth of the concept.

10.3.4 Night Version of Sea Hunt

It was suggested that an owl be used in a night version of the Sea Hunt airborne search system. Considerable thought will have to be given to design of their observation module and the training methods to be employed. The owls may have to be held in place, respond, and be rewarded quite differently than the pigeon. Again, consultations with bird trainers and bird curators at zoos and wild animal parks would prove profitable.

The Naval Ocean Systems Center or a private contractor could develop an experimental model of this system. It would take about a year to develop such a model.

10.3.5 Suspect Marijuana Smuggling Ship Selection

The feasibility of using animals including birds to identify ships which may be carrying marijuana should be demonstrated. Preliminary evaluations suggested that the most viable concept involves sucking air samples into an airborne vehicle flying over each ship. An animal in the airborne vehicle would sniff the samples for the odor of marijuana. While the feasibility of this concept is being tested, the other concepts might be given additional consideration.

Two critical system development questions for which answers should be sought immediately in the project are: 1) What is the sensitivity of different animals to the odorant in marijuana, and 2) How should the air samples be delivered to the animals? If a small animal is used, it might be lowered in a capsule over the ship and sniff the air directly through a port in the capsule.

Initial work on this concept (evaluating candidate animals, training behaviors, and developing the air sample delivery system) can be done in a laboratory setting. Then a test facility could be developed in a bay or or land. Finally, offshore flight tests could be conducted utilizing target ships intentially loaded with confiscated marijuana. It is estimated that about eighteen months would be required to develop and test an experimental model of the system.

10.3.6 Harbor Entrance Monitoring for Marijuana Smuggling

Development of this system could be carried out jointly with the previous system up to a point. The animal selection and conditioning effort is the same. There may or may not be additional joint work. That will depend upon the animal chosen, the interrogations and response mechanisms design, the air sample delivery method, and the means of positioning the system downwind of boats/ships entering the harbor.

10.3.7 Inspecting Ships for Narcotics Smuggling

Narcotics detection dogs are available. If the Coast Guard is interested in using these animals to inspect suspected smuggling ships, it is suggested that some shipboard tests be run with animals obtained from the Air Force or U.S. Customs Service. Some adaptations of the animals to working on board ships is desirable to get the best performance. Smelling air from cargo containers on and off ships also should be tried.

In addition, it is suggested that the Coast Guard monitor the work of other agencies on use of rats and gerbils for explosives detection. If results are positive, the Coast Guard may consider a similar development effort to use these animals for narcotics detection on board suspect ships.

10.3.8 Facilities and Ship Security Systems

There are three missions which call for a security system to protect offshore and waterfront facilities and ships from intruders. Those missions

are theft control, terrorism control, and protection of offshore assets as a military operation. A system utilizing a bird as an intruder detection sensor could, in large part, perform all three missions. It was suggested that a bird with good night vision, such as an owl, be employed.

There would be substantial engineering and behavioral efforts involved in development of an operational system. The first stage of this project should concentrate on the animal selection and behavioral aspects of the system. Candidate species should be selected after more study of the literature on bird vision and behavior and consultation with bird training and behavior experts. Then an experimental program should be started to develop system behaviors. Selected birds must be conditioned to scan water surfaces, the sides of facilities and ships, and piers. They must respond upon detecting small boats and people (swimmers or people climbing onto a facility or ship). Experimental hardware will have to be developed to support the behavioral work. A work station, response devices, reinforcement mechanisms, and programming electronics will have to be built. However, engineering development of the animal's observation booth and associated equipment can await satisfactory demonstration of system capability. That milestone should not take more than two years to achieve.

There are a few different ways of obtaining support for development and operation of this system. The Coast Guard may choose to undertake feasibility demonstration on its own. Alternatively, support can be sought from the Navy as part of one of its security programs (e.g., WIDS-Waterborne Intrusion Detection System or SNWS-Shipboard Nuclear Weapons Security). Further development and acquisition of the system also could be jointly supported. Once the system is operational, the Coast Guard could encourage, or, if the situation demands (i.e., terrorist attacks on offshore facilities do occur), require industry to procure and use the system.

10.3.9 Cruise Ship Passenger and Luggage Inspection

If dogs are utilized to inspect passengers for explosives (with the passengers in booths separated from the animals), the system could be procured from the Air Force Military Working Dog Center. Use of another animal (such as a pig with greater olfactory sensitivity) would require some development work. For the present, it is suggested that an analysis be performed of what resources would be necessary to screen passengers boarding a cruise ship and perhaps experimentally evaluate the concept.

For luggage inspection, dogs like those trained for the FAA could be procured from the Military Working Dog Center. The Coast Guard should also monitor experimental work on use of pigeons to screen x-ray pictures of luggage.

10.3.10 Environmental Monitoring

The Coast Guard might evaluate potential use of the luminescent bacteria water quality testing system described earlier (Section 6.7.2). It also could collaborate with the Environmental Protection Agency in supporting research to develop strains of bacteria sensitive to specific pollutants. At the least, the Coast Guard should monitor advances in research on use of bacteria as bioindicators and be alert to their potential utility as environmental protection problems as Coast Guard responsibilities in that arena change.

10.3.11 Military Systems

A dialogue should be carried out between the Coast Guard and the Navy on Coast Guard missions during different types of hostilities. The potential procurement and use of animal systems to perform those missions should be discussed. The Navy is best prepared to develop and produce the systems. The Coast Guard should maintain cognizance of some systems and perhaps have some personnel trained in their use.

10.3.12 Public Relations/Promotional Symbol

A different type of concept than those previously expressed is utilizing an animal as a symbol to foster a good public image of the Coast Guard and promote specific causes, such as boating safety. This project can either be handled by the Coast Guard or a public relations firm brought in to manage the endeavor. The only animal work required is the training of a few animals for public appearances and media presentations.

10.3.13 Bionics

The Coast Guard should monitor and possibly support research and development work being performed elsewhere on bionic sonars, artificial noses, and automated pattern recognition. When substantial advances are noted in those technologies, their potential application to Coast Guard missions should be reconsidered.

10.3.14 Overall Monitoring Effort

Specific system development projects were suggested in the previous paragraphs. Those involved the more promising system concepts and immediate or important Coast Guard needs. However, needs have a way of changing, discoveries are made of animal capabilities, and new ideas occur on how to employ animals. A continuing project is suggested to:

- Maintain awareness of what is being done in animal research and systems development in other government agencies, universities, research institutes, and industry. Liaison should be continued with those working on animal projects.
- Analyze Coast Guard missions and projections with a sensitivity to protential applications of animal systems.
- Prepare program recommendations for animal research, systems development, and utilization.

11.0 CONCLUSIONS

The increase in economic and recreational activities in the marine environment over the next twenty-five years will place greater demands upon the Coast Guard. The basic nature of several Coast Guard missions will stay the same, but the workload will increase and the means of performance may have to be modified. Vessel traffic safety exemplifies such a mission. Other demands, such as protection of offshore facilities from terrorism, will be new to the Coast Guard. The burden of a few responsibilities may be eased, for example, in the face of requirements for search and rescue services, greater participation of states and cities may be sought.

There are animals which have special capabilities that can be used to help perform some Coast Guard missions. In selected animals, the capabilities superior to man's are the senses of smell, sight, and hearing (especially echolocation). Those sensory capabilities are sometimes complemented by other desirable qualities such as attentiveness, which is difficult to maintain in man. The diving and swimming capabilities of marine mammals and the flight of birds also may be used in conjunction with their extraordinary sensory characteristics.

Several of the system concepts to use animals for Coast Guard missions warrant consideration for development and evaluation of experimental models. In that category are systems for day and night SAR, marijuana smuggling interdiction, and facility and ship security missions. The first two of those missions currently are highly demanding of Coast Guard resources and are expected to continue well into the future. If terrorism is directed against the United States, the onset of the security mission in the economically growing marine environment could be dramatic.

There are animal systems which are being used or developed by other organizations. Security, environmental monitoring, and military support tasks

are performed. Those systems might be modified or used directly by the Coast Guard. The Coast Guard may wish to evaluate those systems for its own use, support additional development, or make plans to procure and employ the systems if and when they are needed.

An animal symbol could be used to foster Coast Guard-public relations and stimulate interest in certain programs such as boating safety, recruiting, etc. The symbol could be used on published materials, and a few live animals could be trained for public appearances.

A modest but continuing effort should be devoted to analyzing Coast Guard missions with respect to potential applications for animals. That project should maintain awareness of animal behavior and capabilities research and of system developments.

In summary, there are limited, but potentially valuable, uses of animals by the Coast Guard. Some are worthy of immediate attention. Other applications may prove worthwhile in the future.

APPENDIX A

REVIEW OF ANIMAL CAPABILITIES

APPENDIX A

A.1 VISUAL CAPABILITIES OF SELECTED ANIMAL GROUPS

Light sensitivity of some type exists in every phylum of the animal kingdom with maximal capabilities in most parameters of vision present in birds. Man has excellent overall vision with respect to most animals but frequently other organisms surpass humans in particular parameters of vision. For example, many insects are sensitive to ultraviolet and a few are sensitive to infrared light; sensitivity o the plane of polarized light is common in invertebrates; and many mammals are sensitive to light intensities lower than humans can perceive, etc. These and other differences and comparisons are summarized in Table A.1. The unusual capabilities of four animal groups with potential usefulness will be described below. A fifth section will discuss unique but probably less useful visual capabilities in a variety of other animals.

A.1.1 The Octopus (*Cephalopoda*)

A good recent review of *Cephalopoda* biology, with special reference to the octopus, is contained in the Octopus by M. J. Wells, 1978.

The anatomy of the octopus eye is similar to man and its capabilities are comparable in many respects but important differences exist. Octopus eyes are fixed in their sockets and binocular vision is absent. This is not the case however in the related squids and cuttlefish which have good binocular vision. Also, the octopus eye houses a slit-like pupil that is always maintained in a horizontal position for a visual environmental reference. In addition, the eye of the octopus is in focus for a few meters distance when relaxed and accomodation must occur to focus at other distances, however, this accomodation mechanism is not as quick and accurate as in humans and certainly not strong enough for an octopus to focus adequately out of water. Color discrimination is similarly poor with respect to man but does exist to some degree, (Menzel, 1979). The image perceived by an octopus is quite different from human standards as exemplified by the following facts: the octopus cannot be trained to discriminate between diagonal lines oblique to the left or right, although it can discriminate horizontal from vertical lines and octopi only show behavioral responses to size differences of at least 100% tending to simply attack most small objects and escape from large ones usually without regard to visual details, (Wells, 1978).

Definite advantages of octopus vision include sensitivity to the plane of polarized light, slow but very good adaptation to low light intensities (correlated to its nocturnal predatory lifestyle) and a wide field of view. The acuity of octopus vision has been tested to be at least 17 minutes of arc, the best measured in any invertebrate.

A.1.2 Fish and Sharks

Sharks, skates and rays, i.e., the *Elasmobranchii*, have good visual sensitivity to movement and contrast especially at low light intensities, (Costeau, 1970). An indication of this movement sensitivity is the high flicker fusion frequency (45/second) found in lemon sharks, (Gilbert, 1963). The minimum intensity of light in which sharks can see is about 1/10th of the minimum threshold for humans, (Gruber, et al, 1977). However, this high sensitivity to light is inevitably accompanied by correspondingly poor acuity and little or no color vision, (Gilbert, 1963). Sharks typically have a wide field of view, and dark adaptation covers a wide dynamic range and is rapid, (Gruber, et al, 1978). The shark eye at rest is in focus for about 50 feet and accommodation must occur for vision at other distances. Vision in all marine animals is limited by water clarity and is normally under 100 feet in range. The visual range, and in fact all the above mentioned characteristics, are consistent with the shark's role as a nocturnal predator.

Fishes can be conveniently divided into those that inhabit the photic zone (where sunlight penetrates), and those that inhabit the deep sea. Generally speaking, most photic zone fishes can discriminate colors although such color discrimination is less than what humans achieve. Furthermore, the breadth of the frequency range over which fish are sensitive is similar to man but shifts increasingly toward shorter wavelengths in species that inhabit progressively deeper waters, (Muntz and McFarland, 1977; Yeager and Thorpe, 1970). Most photic zone fish have a fovea and, although acuity is variable with lifestyle, the best acuity in fish equals man, i.e., 1 minute of arc, (Muntz and McFarland, 1977). Also some fish are highly sensitive to contrasts. Binocular vision is variable in photic zone fish and most tend to have a wide field of view. Accommodation capabilities are also variable. Finally, it is noteworthy that once again there are competing goals between acuity and color vision on one

hand and low intensity vision on the other, such that those fishes with high acuity and good color vision have relatively poor low intensity vision. This capability tradeoff is inherent in the physiology of most visual receptors because there are basically two receptor types competing for space in the retina, each corresponding to one capability, and thus more of one capability implies less of the other.

The deep sea fish retina contains almost all rods and therefore is sensitive to very low light intensities, especially in the short wavelengths, (Boden and Kampa, 1974). Acuity and color discrimination are, of course, poor. Other characteristics including binocular vision, tubular eyes and a limited field of view are adaptations that further enhance low intensity vision, (Lockett, 1977). Deep sea fish species often produce weak light of their own, and this ability is employed in many life sustaining functions, (Clark and Wertheim, 1956).

A.1.3 Birds (*Aves*)

Two good general references for avian vision are Marler and Hamilton, 1966 and Walls, 1963. More up-to-date information is available in the Handbook of Sensory Physiology.

The most outstanding adaptations of visual capabilities are found in the class Aves. The fovea is a slightly depressed retinal area of highly concentrated receptor cells. The fovea usually corresponds to an area of high acuity and good color vision. In man this area subtends a visual field about the size of a dime at arms length. In some birds, however, the fovea achieves great size and complexity; for example, many birds of prey have two foveae in each eye for wide field instantaneous scanning and prey detection. Generally, the foveal area in birds is species specific in size and shape depending on the birds particular lifestyle and requirements. For example, hawks, eagles, ducks, swallows and shorebirds all have a long foveal area parallel to the horizon such that they can instantly survey a wide view in great detail without "scanning" across the horizon as humans must.

The acuity in the foveal area is very high and is best in hawks, eagles, and vultures, (14 seconds to 70 seconds of arc). One old world

vulture, Buteo buteo, has a foveal cone density so high that it can discriminate 8 seconds of arc, or about 8 times man's best (Milne, 1967).

Movement sensitivity is closely related to acuity but employs additional components. For example, the pigeon's acuity is the same as man's, however its movement sensitivity is much better. Pigeons can detect movement of 15°/hr in a rotating object such as the hour hand of a clock (Meyer, 1977). The high movement sensitivity of pigeons is also indicated by their high flicker fusion frequency (Meyer, 1977). (Note in Table A.2 that man has a flicker fusion frequency of about 25/sec. but insects achieve as much as 250/sec.) Other birds with high acuity can also be expected to have good movement sensitivity.

Contrast detection is another capability closely related to acuity. In addition to foveal cone density, the presence of oil droplets in the retina aids in heightening contrasts between objects, a capability especially useful on misty and overcast days (Welty, 1975). However, this contrast sensitivity is obtained at the expense of color discrimination in the green-blue due to selective absorption of those wavelengths by the oil droplets.

Some species of birds with high acuity also have excellent (i.e., similar to man) color vision. However, many birds have retinal oil droplets and thus have limited color discrimination in the blue-green range as just mentioned. Exceptions include the hawks, parrots, owls and woodpeckers which have no oil droplets and thus discriminate color in the green-blue as well as man (Hess, 1960). Nocturnal birds can be expected to have poor color discrimination as exemplified by owls which are apparently red blind. It is noteworthy that pigeons are capable of detecting ultraviolet light as well as the plane of polarized light (Kreithen, 1979).

As previously mentioned, low intensity vision and the high acuity-high color vision just described are competing goals. Most birds are diurnal, require high light intensities for vision but have excellent acuity and color vision. A few nocturnal species have sacrificed these goals in order to see at night. These birds include nighthawks, poorwills, oil birds (Nicol and Arnott, 1974), and the equisitely adapted owls. Owls can see in 100 times

less light than humans and yet are still capable of matching our day time acuity. Also, crows are capable of intensity discrimination comparable to man whereas most other diurnal birds are not.

The field of view is typically very wide in birds. In those species without a wide field of view the mobility of the neck is such that vision around 360° is rapid and efficient, for example, the owl's field of view is relatively narrow, but it can rotate its head through 270° thus allowing 360° vision. Binocular vision is also important for most birds because depth perception is essential for navigation and safety in flight. The predatory birds, e.g., the hawks and owls are notable in this respect with 60°-70° binocular overlap.

With the aforementioned visual capabilities it is obvious that birds can discriminate details of form, shape, color and pattern etc. It has also been demonstrated that birds can be trained to respond to visual details, even to the point of "constancy" or concept formation as detailed for the pigeon in Section 5.0 of this report.

One final avian visual capability is noteworthy. Several types of birds are capable of good vision both in air and under water. By various adaptations the diving ducks, loons, auks and cormorants can accommodate very strongly to allow good vision under water. Some insectivorous birds also accommodate very strongly but are not specifically adapted for under water vision.

A.1.4 Seals and Sea Lions (*Pinnipedia*)

Sea lions have strong accommodation and thus see well both in and out of water, and in addition, also have good vision in low light intensity. Acuity of vision is 4-6 minutes of arc under water even in low light (2×10^{-4} mL). The same level of acuity can be achieved in air but moderate light is required. At low light intensity (2×10^{-4} mL) acuity in air is only about 8-10 minutes of arc (Harrison et al., 1968).

Several pinniped species have been trained to discriminate size differences of 6%, the best species being the sea lion with a discrimination limit of 3% (Harrison et al., 1968).

Good binocular vision is present in pinnipeds as an adaptation for pursuing and capturing fish. Intensity discrimination is also good and helps compensate for their almost complete lack of color vision.

Pinnipeds are fast learners relative to most mammals and have been trained to discriminate various geometric shapes containing small differences. Visual learning was equally good in the California Sea Lion, the harbor seal, and the stellar sea lion, (Harrison et al., 1968).

A.1.5 Other Visual Capabilities

Other animal groups possess visual abilities with no obvious utility, yet these abilities are noteworthy inasmuch as they may be useful in conjunction with some other capability.

Many insects are sensitive to both the plane of polarized light and ultra violet radiation. More rarely, certain insects are sensitive to infrared light and even X-rays. Insects also possess an extremely high flicker fusion frequency and thus also good sensitivity to movement. Some insects see color, others produce light of their own and a few predatory insects even form visual images. However, insects are limited in a general way by severe myopia and lack of accommodation, and in addition require high light intensity to achieve any visual response.

Reptiles possess moderately good vision but are relatively unremarkable with the exception of geckoes, which have highly mobile eyes and excellect low intensity vision.

Among mammals man has very good vision, but many others see better in dim light. In fact most mammals have completely sacrificed acuity and color vision for the ability to see better at night.

Table A.1 Parameters of Visual Capabilities in Selected Animal Groups

GROUP	ACUITY	FOVEA	COLOR DISCRIMINATION	FIELD OF VIEW	BINOCULAR VISION	THRESHOLD SENSITIVITY	RELATIVE INTENSITY DISCRIMINATION	WAVELENGTH RANGE	POLARIZED LIGHT SENSITIVITY	IMAGE PERCEPTION	MOVEMENT SENSITIVITY	FLICKER FUSION FREQUENCY	ACCOMMODATION	MEDIUM	ADAPTATION	PRODUCTION
Lower invertebrates ( )	SIMPLE P[illegible] [illegible] SENSITIVITY RANGE EXTENDS SOMETIMES INTO THE U.V.															any species
[illegible] (29)	[illegible] best [illegible]		present [illegible] (21)	wide	[illegible] absent, [illegible] and [illegible] present	low	good	max. pigment absorption at 470-500 nm	present	present in [illegible] can't see diagonals			good	water	very good but slow several hours	
Spiders		none		short-range		low in wolf spiders				rarely	good			air only		
[illegible] and [illegible] ( ) (21)	[illegible]	none	[illegible]	very wide	extensive overlap	10^9 x threshold of man		UV [illegible]	many species [illegible]	some	excellent	good	none; nearsighted	air & water		
[illegible], bees, [illegible] wasps ( ) (21) (20)	[illegible] 100 [illegible] 200 [illegible] at field edge	none	present [illegible] at 440 nm [illegible]	wide		1/1000 full sunlight [illegible] poor	25% change only 12 shades of grey	bees UV + no red. max. [illegible] at 340, 440 & 540 nm [illegible] X-rays	many species bees flies beetles etc.	rare - some bees butterflies mantids dragonflies	excellent 5X man in most insects	200/sec	none; nearsighted	air		beetles, flies, etc
Other	drosophila, 1000 man mantids and dragonflies better	present in mantid	present in flies, cockroaches and moths	wide	predator insects	poor	drosophila, only 3 shades of grey	many insects U.V. sensitive [illegible]				most insects very high, up to 250/sec.				
Sharks, Skates, and Rays ( ) ( ) (3) ( )	poor	little or none	little or none	wide	absent	1/10 man. very low & good contrast sensitivity also pineal organ has low threshold	good		none	present	excellent	45/sec in lemon shark	present	water	rapid and wide range	
[illegible] Photic Zone (8) (31) (25)	varies with lifestyle — best are similar to man	present, cone density can approach man	present in Cyprinidae most probably trichromatic	wide	variable	good	sensitivity good	generally max. abs. 300-810nm		present			good	water only		
Fish Deep Sea ( ) ( ) (17)	poor to moderate	present in some w/ [illegible] cell density	none or poor	narrow	present	10^{-5} mw/cm²/nm or 650 quanta/sec. at 470 nm.	good	sensitivity shifted to blues max=455nm		present			present	water		any species
Amphibia	very poor	none		wide						none pattern & shape	good			air	present	
Turtles, Reptilia	moderately good		present in most	very wide	present			max. [illegible] absorptions 560 & 470 nm		present	good- otherwise vision poor esp. long distance			air	rapid	
Geckoes ( ) ( )	poor	present in lizards	[illegible]			excellent										
Birds, Hawks, Eagles, Vultures ( ) (30) (20)	[illegible] sec-[illegible] 0 sec.	large, 2 fovea in hawks, eagles & swallows	diurnal birds [illegible] [illegible] than man	wide & downward directed foveal area	60-120 present & stereoscopic	poor		those with oil droplets see less of green and blue		present 3X man	excellent		present and good (man)	air	poor	
Other Birds (26)	diurnal best, [illegible] Passerines [illegible]	large horiz. fovea in [illegible] & shorebirds [illegible] to scan	nocturnal birds less [illegible] diurnal [illegible] like man	[illegible] wide	variable [illegible]	good in nighthawks, poorwills, nite-birds (26)	crow is similar to man, most birds less sensitive	those with oil droplets see less of green and blue	present in large waders e.g. herons (probably)	present	usually better than man		penguin poor chick 3-10 diopters, insectivores 10-20 d, cormorant 40-50 diopters	penguin [illegible] only [illegible] ability cormorant both air & water	usually [illegible] and [illegible]	
Pigeons & Doves	[illegible]	large area of [illegible]	better than man	[illegible]	none			[illegible] man in the yellow-red, high sensitivity in U.V.	present	similar to man	15° [illegible]	highest vertebrate known (23)	8-12 diopters	air	poor	

[illegible]	[illegible]	[illegible]	[illegible] DISCRIMINATION	[illegible] VIEW	B[illegible] VISION	THRESHOLD INTENSITY	RELATIVE INTENSITY DISCRIMINATION	WAVELENGTH RANGE	[illegible] LIGHT SENSITIVITY	[illegible]	[illegible]	[illegible]	[illegible]	MED[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	60-[illegible]	excellent stereoscopic [illegible]	[illegible] candles at [illegible] 10x less [illegible] than man	excellent [illegible]	[illegible] red but [illegible] green [illegible]		[illegible]			[illegible]	[illegible]	[illegible]	
Mammals [illegible]	[illegible]		none or poor in most except man and primates	[illegible]3°	[illegible]30°	excellent	better than man in most mammals		none	[illegible]				variable otters and beavers both in and out of water	good	
Other Terrestrial	opossum [illegible] min, dogs have poor distance vision, large mammals have poor acuity		some present in cats	rat 205° grey squirrel 300° goat 320° rabbit 360°	present in predators	also rodents and foxes are good		bats and rats [illegible] sensitive	none				[illegible] +3 D; horse & sheep poor; rodents poor			
Seals	water 4-6 min, air 4-6 min. w/modest light ~6% size diff.	none	none shown yet	variable	present	at least as good as man			none	present			strong for water & air vision	water & air	rapid	
Man	.5 to 1 min.	small central	trichromatic	190°	present	1×10^{-9} full sunlight	discriminate 1% change in illum nat or ~500 shades of grey	380-720nm	none	present		25/sec. to 50/sec.	child: 13-20 diopters man of 20: 10 diopters man of 40: 4-6 diopters		slow 20 min	

A.2 THERMORECEPTION IN SELECTED ANIMAL GROUPS

Parameters of thermosensitivity in selected animal groups are listed in Table A.2. Thermosensitivity is limited to relatively few animal groups and is only well developed in a few fish, insects, and reptiles.

Most animals have poor thermosensitivity with respect to man-made thermosensitive instruments. For example, mammalian thermoreception is largely reflexive and utilized for thermoregulation or pain reception. Thermal behavioral stimuli in mammals are usually limited to gross environmental temperature changes, although a man can detect a warming of .001°C/sec. at 35°C as the entire body surface is so stimulated (Alexander, 1975). Birds are similarly quite limited in this sensitivity with the notable exception of the incubator bird Leipoa ocellata (Firth, 1959). Marine invertebrates (bottom fouling organisms) show some thermal selectivity during developmental stages when mobile larvae choose sites for colonization. The Elasmobranchii also show thermosensitivity, but this is a by-product (thermoelectric transduction) of their outstanding electrical sense (Hodgson and Mathewson, 1978).

Among animals with good thermosensitivity, the reptiles, specifically pit vipers (Crotalidae), are the best examples. A change in temperature of 1×10^{-4}°C at the receptor surface is adequate to elicit a behavioral response (Milne and Milne, 1967). Some fish also show good thermosensitivity, being able t detect a temperature gradient of .03°C from the head to the body. Among the Arthropoda, blood sucking species that depend on warm blooded hosts often have sensitive and rarely directional thermoreception (Richards and Davies, 1977). In addition, social insects (bees, ants, and termites) have thermosensitivity which allows thermoregulation of the colony within about 1°C.

Table A.2 Parameters of Thermosensitivity in Selected Animal Groups

GROUP	SENSITIVITY	FUNCTION	THERMORECEPTIVE ORGANS
Lower Invertebrates	many species have sensitivity to Absolute temperature within a few °C	for successful larval colonization	
Arthropods. 2 5 6			
ticks	detect a change of .5°C	host detection	Variety of Organs
Flies & Mosquitoes	detect a change of .05°C at [illegible] cm.	host detection	
Fleas and Butterfly Larvae	detect differences of a few °C	host detection and appropriate habitat selection	
Lice	detect mammalian body heat from a few inches	host detection	
Bed Bugs	detect mammalian body heat from several feet above	host detection	
Bees and Termites	sensitive to Absolute temperature within 1°C. Bees maintain hive at 13°C at ambient temperature of -40°C	hive or colony thermoregulation	
Sharks, Skates and Rays 4	.01°C change at the thermoreceptive surface	probably water temperature via thermoelectric transduction	Ampullae of Lorenzini
Fishes	.03°C temperature difference from head to body. Also recognize Absolute temperature within 1°C	habitat selection and depth orientation	
Reptiles 5 Pit Vipers and some boas and pythons	blindfolded rattlesnakes can locate and strike a rat from 50cm., can detect objects 1°C warmer than background. The equivalent change in temperature at the receptor surface is 5×10^{-4} °C	prey detection and temperature regulation	labial heat sensitive pits
Birds Megapodes 3	Absolute sensitivity to 33°C within 1/10 °C	nest incubation	beak receptors
Mammals 1	Thermoregulation commonly maintains body temperature $\pm$ 0.1°C. Thermosensitivity is largely automatic and reflex.		
Rodents	Absolute temperature sensitivity within 1°C		heat sensors in legs and scrotum - cold sensors in hairy skin and face
Other Mammals e.g., cat, dog, monkeys have conscious thermoreception via cutaneous thermoreceptors and pain receptors in different parts of the body for various functions.			
Man	at 35°C a warming of .001°C/sec. is detectable	thermoregulation	thermoreceptors in skin

A.3 CHEMORECEPTION IN SELECTED ANIMAL GROUPS

It is difficult to characterize chemoreception briefly. However, the following short introduction along with Table A.3 will provide a general idea of relative chemoreceptive capabilities of animals.

Chemoreception can be conveniently divided into three categories depending on the type of receptor and distance from the stimulus at which it is adapted to function. The most primitive type of chemoreception is the common chemical sense in which the receptors are relatively non-specialized areas of skin surface or membranes and the stimulus is usually an irritant which must be applied directly to receptor areas to elicit a response. This contact chemoreception is similar to the sensitivity of the human eye and mucous membranes to salt soap and other irritants. The common chemical sense generally has low sensitivity and specificity and provides a relatively crude system for lower animals to detect basic environmental stimuli. Many vertebrates, sharks for example, have retained this type of chemoreception to some degree. A second type of chemoreception is gustation or taste. Gustation is characterized by specialized receptor organs and responses to stimuli that must be presented on or very close to those receptor organs. Thus, gustation is also a contact chemical sense, although this criterion tends to break down in aquatic organisms. Gustatory specificity and sensitivity are moderate. Taste is commonly associated with vertebrates, but insects often have equal or better abilities. Olfaction (or smell) is the third category of chemoreception and is by far the most advanced in terms of specificity and sensitivity as well as the greater distances at which chemical stimuli are detected. Highly specialized receptors of many types are usually housed in a specialized organ for olfaction. Olfaction is a primary source of environmental information in insects, fish and most mammals.

Chemoreception can be further characterized, like other sensory systems, by adaptation, i.e., the loss of response in the presence of a continuing stimulus. It should be noted that chemoreceptive adaptation occurs strongly in vertebrates usually with rapid onset and recovery.

Present research is at the level of working out the mechanism of chemical stimulation of receptor cells, i.e., how chemoreceptor systems can respond to the huge quantitative and qualitative variety of chemical stimuli. Other research involves improving methods of measurement. Recent olfactory and gustatory measurements in the research literature are inconsistent. These inconsistencies are the result of wide natural variation in chemoreceptive ability from individual to individual within the same species, and also due to variations and inaccuracies in the methods of testing. Thus, accurate measurement of extremely sensitive chemoreception is still a significant problem. For example, human thresholds would seem to be easily measured but man has been found to vary 1000 fold in his olfactory sensitivity to certain compounds, (Amoore, 1971); and different investigators have found absolute thresholds of human taste that vary up to two orders of magnitude. In order to remove individual variation and testing errors from chemoreceptive measurements the methods for testing are becoming increasingly statistical and comparative.

Thus, characterizing chemoreception in a quantitative way is sometimes hazardous, but comparative and qualitative statements can be made with some confidence. Table A.3 characterizes animal chemoreceptive abilities by giving a representative stimulus compound or compounds and listing: the absolute threshold sensitivity to that stimulus, how specific the response is to the stimulus as opposed to related odors, how much of a change in concentration of the stimulus is detectable, and if the capability is directional. Also, the type of chemoreception (olfaction, gustation, or common chemical sense) is noted. The stimuli listed are those that have low thresholds due to some biological significance to the organism in question. Occasionally stimuli of standard laboratory chemicals are given for comparative purposes.

In general chemoreception, like vision, is present in all animal phyla. It is probably the most ancient of all sensory systems. It functions as a mode of sensory input basic to many life processes including feeding, reproduction, communication and orientation. Invertebrates possess highly

variable abilities with insects and molluscs outstanding. Among vertebrates fish and mammals have excellent chemoreception, but birds, bats, primates, amphibians and reptiles are relatively unremarkable, (Parsons, 1971). In this sensory capacity humans are exceptionally poor with respect to the entire animal kingdom, being surpassed by organisms ranging from pigs to bacteria. As was done previously, animal groups of potential usefulness will be discussed separately in more detail below.

A.3.1 Bacteria

Many bacteria have sensitivity to biologically relevant compounds in the range of a few parts per million, however, specificity is poor. Chemoreception is accomplished by an unknown contact mechanism. Usually individual strains are exceptionally sensitive to one or a few compounds and respond to such compounds by movement or a biochemical change etc.

There are two fundamental problems associated with utilizing bacterial chemoreception. First the chemosensitivity must be somehow directed specifically toward a particular useful stimulus, and second it is necessary to have some quick and easily observable indicator of the bacterial response. The first problem can be overcome by selective breeding of bacteria to obtain strains sensitive and specific to appropriate stimuli. The use of mutagens to increase variability from which selection can occur, and the rapid generation time of bacteria would both facilitate this process. The second problem can be solved by several methods. For example, specific metabolic products only produced in the presence of the stimulus compound could be indicated by chemicals that change color in their presence. Another indicator that has been used is photoemission or biolumenescence. The now discontinued biosensor division of Bauscn and Lomb researched and tested such a detection system utilizing bacterial photoemission as an indicator. Appropriate hardware introduced gases from fuels, explosives, drugs, etc. to a bacterial solution and then sensed the change in photoemission and indicated the presence or absence of a particular stimulus. Different strains were sensitive to different gases in the p.p.m. range, (Kent, 1974). Although bacteria have inherent problems for development, in use they have the advantages of being small, inexpensive, fast, and easily expendable.

A.3.2 Insecta

The problems and advantages associated with the use of insect chemoreception are similar to those associated with the use of bacteria. Advantages include speed of operation, expendability, small size, low expense, and extreme sensitivity. The problems are to find organisms sensitive to the stimulus one desires to detect (e.g., explosives or drugs) and then to obtain observable responses. The problem of finding organisms sensitive to a specific stimulus may be overcome by selective breeding, (Wright, 1976). Insects have tremendous genetic variability within natural populations from which appropriate individuals can be selected and bred, (Kikuchi, 1973). This natural genetic variability can be supplemented by the use of mutagens (e.g., UV. light, X-rays or chemicals) to further facilitate obtaining appropriate genetic types. Furthermore, another method called larval conditioning can add environmentally determined preferences to the genetically determined preference to produce even more sensitive individuals. The second problem, i.e., the observability of the response, may not be severe because insects often respond with predictable, easily observed, fixed and stereotyped behavior to the presence of a stimulus.

Insects utilize a variety of chemical receptors including sensory hairs, pits and antennae which can be located all over the body. Some of these receptors are highly specific and others are generalized with responses occuring to a wide variety of compounds including carbon dioxide, water, sugars and amino acids, etc. All three aforementioned types of chemoreception are present as well as unique types that defy simple classification. Gustation in insects includes sensitivity to the four "tastes" to which humans respond (i.e., sweet, sour, bitter, salt) and also specific receptors for ketones, aldehydes, alcohols, organic salts and glycols, etc. Olfaction is also highly developed in insects and responses are predictably most sensitive and specific to compounds that have some biological relevance to the species in question. For example, it is important for bees to detect changes in the concentration of CO_2 and moisture in the hive. Thus they have developed these exceptional abilities (see Table A.3). Similarly, blowflies are sensitive to carrion odors by which they find food and reproductive sites, (Deither, 1962 and Collias, 1980). Another example is the "green smell" of plants (trans-2-hexanal) which is attractive to several species of insects

in extremely low concentrations, (Gesteland, 1971). A final example of sensitivity to biologically relevant compounds is the mosquito's sensitivity to CO_2 and lactic acid with which it can smell a mammal within 15 feet, (Kaissling, 1971).

Insects are physiologically hardy and neurologically simple and therefore pieces of their bodies can be isolated and possibly used for chemoreception. For example a bee abdomen severed at the node will respond with characteristic movements to qualitatively and quantitatively different stimuli applied at the node. This "signature" can be quite sensitive and specific, (Pence and Lomax, 1973). Certain drug administrations can be detected in the near part per billion range. The bee abdomen test system also has been utilized for detecting specific pollutants, analyzing soils and certifying water purity.

The most outstanding examples of insect olfaction are to be found in responses to pheromones. Pheromones are substances secreted by one animal that effect the behavior of conspecifics. The behavioral effects of pheromones can be immediate or may serve a "priming" function for some later behavior. Typically pheromones are used for aggregating insects, attracting sex partners, signaling alarm, inducing physiological changes, orientation and other types of communication, (Von Frisch, 1954). Pheoromones, especially sex attractant pheromones, are characterized by extreme potency and specificity. A few molecules of the sex attractant pheromone bombykol will elicit a response from a male silkworm moth, (Kaissling, 1971). Pheromones are also characterized by intermediate molecular weights which allow enough complexity to be highly specific yet also enough volatility to dissipate and lose effectiveness in a short period (usually minutes). This type of chemical communication is surprisingly common in insects, nine orders of insects have been shown to utilize pheromones thus far. These include the major orders; Lepidoptera (moths and butterflies), Orthoptera (grasshoppers, cockroaches and crickets), Coleoptera (beetles), Hymenoptera (bees, ants and wasps), and Isoptera (termites).

The structures of some pheromones have been determined and thus synthetic production of such compounds is possible. Use of pheromones for

pest insect control is thus becoming increasingly widespread. Grain weevils, cucumber beetles, bark beetles, the black carpet beetle, the sugar beet wireworm, the cabbage loper moth, the pink bollworm moth, bees and some cockroaches are among insect pests now controlled by pheromonal systems.

In conclusion, application of insect chemoreception requires the solution of some problems but has significant advantages if such problems are overcome. Olfaction is the best chemoreceptive sense insects possess, responses being best for biologically relevant stimuli. Finally, sex attractant pheromones are among the most powerful and specific chemical stimuli known, and thus may be useful without modification.

A.3.3 Marine Animals

The octopus possesses contact chemoreceptors in the rims of its suckers which are 100 times as sensitive as the human tongue to sweet, sour, and bitter stimuli, (Collias, 1980 and Wells, 1978). Squids have similar thresholds. One other mollusk is the gastropod genus *Nassarius* the members of which are extremely sensitive to food related compounds, (Grant and Mackie, 1974).

Sharks and rays (the Elasmobranchii) have developed chemoreception systems of excellent sensitivity and directionality. Directionality is achieved via two methods; either by successive olfactory sampling in a search pattern to determine the direction of an odor gradient, or by simply swimming into the current when odors are perceived, (Mathewson and Hodgson, 1972). Effective stimuli are species variable but are usually food related and have strong effects on feeding behavior. The common chemical sense is well developed in sharks and functions mainly to alert the shark to harmful chemicals in the water, (Gilbert, 1967). Examples of such irritating stimuli include decaying shark flesh, quinine, secretions from the sea slug *Aplysia*, extracts of the Curviers gland of Holothurians (i.e., sea cucumbers), secretions from the flat fish *Pardachus marmoratus*, phenol, allyl isothiocyanate, nitrostyrene, bromide and phenacyl chloride, (Hodgson and Mathewson, 1978). Gustation is less pronounced and is utilized mainly to evaluate the acceptability of food but may be totally disregarded in the situation of a feeding frenzy. Olfaction is the remarkable chemoreceptive mode in sharks and rays and is responsible

for long range detection of food. Sharks are sensitive to many odorants in the p.p.m. range, (Gruber and Myrberg, 1977), but food-related stimuli are much more effective as exemplified by hammerheads turning their heads in the direction of a 10^{-4} p.p.m. grouse fish extract stimulus, (Tester, 1963). An indicator of this olfactory sensitivity is that sharks are capable of smelling the difference between calm and distressed fish by detecting minute unique odorants produced by alarmed fish.

Some fish have impressive olfactory abilities as shown in Table A.3 for the minnow *Phoxinus*, (Grant and Mackie, 1974). Obviously, this fish, via olfaction, is vastly superior to man in man's four basic gustatory capabilities. Blinded minnows have been shown to discriminate between certain alcohols at levels of about 5×10^{-4} p.p.m., (Grant and Mackie, 1974). Because of this alcohol sensitivity minnows have been used as bioindicators of lake pollution via responses to the pollution indicator phenol, (Collias, 1980). Ostariophysian fish produce alarm substances in minute quantities which are released when the skin is damaged sending conspecifics into a "panic". Other olfactory functions in fishes include feeding, recognition of young, parental care, species and sex recognition and homing. Salmon are premier examples of the last category. By virtue of irreversable chemical imprinting on homestream odors during a critical period during early life mature fish return years later to the same stream to spawn, (Wisby and Hasler, 1954). Salmon of the genus *Salmo* have been imprinted on morpholene (a non-natural synthetic compound) in dilutions of 1 part per billion then released, and after their maturation were induced to return up any stream into which morpholene was introduced. Salmon also show observable alarm responses to predator odors such as man, dog, bear, seal and sea lion.

A final example of a potentially useful marine organism with impressive chemoreceptive capabilities is the eel. Certain species can detect particular compounds in concentrations as low as 1 part in 2.86×10^{18} parts water, and can even discriminate between such compounds at similarly low concentrations, (McCartney, 1968). These unparalleled capabilities are limited by individual and seasonal differences, restricted to a few odors, and are related to homing functions.

A.3.4 Birds (*Aves*)

Birds are generally poor at chemoreception. Weight loss as an adaptation for flight, and the scarcity of heavy odorous molecules far above the ground dictated the adaptive loss of good chemoreception. However, recently it has been discovered that exceptions exist.

On the basis of anatomical evidence the best bird candidate for olfactory abilities discovered thus far is the Northern Fulmar, an ocean going procellariform bird, (Wenzel, in press). In fact, most procellariforms possess good olfaction utilized in homing, (Grubb, 1979) and feeding, (Hutchison and Wenzel, 1979). These birds are easily attracted from distances of over 20 miles, to oily stimuli spread on the open ocean, (Wenzel, in press).

Other chemically capable birds are the Trinidad oil bird, grebes, the African honeyguides and the turkey vulture which has been used to locate leaks in gas lines by its olfactory sensitivity to ethyl mercaptan.

Even pigeons whose olfactory anatomy is relatively poor with respect to other birds are apparently responsive to chemical stimuli with sensitivity such that orientation toward the home loft is profoundly distrubed by olfactory occlusion, (Papi, et.al.,1978 a and b and Waldvogel, et.al., 1978).

Olfactory thresholds for all birds have been little researched but will probably be found to be lower than man's but much greater than macrosmatic (sensitive) animals. Thus olfactory sensitivity per se is not the useful capability, but rather its combination with the ability of flight.

A.3.5 Mammals (*Mammalia*)

The olfactory apparatus is well developed in rodents and phylogentically higher mammals except bats and primates. Thresholds to biologically relevant stimuli are generally in the p.p.m. range or better and often responses are directional. Many mammals with excellent chemoreception are not practicable in a system context due to large size, training and handling problems,

inconsistency of responses and other reasons, (Southwest Research Institute, 1974). The most outstanding mammalian examples remaining after such an elimination are dogs and pigs.

Domestic pigs for example the red duroc, have phenomenal olfaction. Pigs are employed to root up truffles (a French fungus delicacy) buried up to a food underground, (Britt, 1978). Pigs are typically large, but for system application miniature breeds of pigs are available that weigh about 200 lbs. These and other pigs are quite intelligent (similar to a dog) and easily trained although they are sometimes reluctant to perform. Pigs have been shown capable of detecting several explosive odors even when the explosive is buried 12 inches underground, (S. R. I., 1974).

Dogs are intelligent, responsive to man, easily motivated and versatile, and therefore can be trained to perform a variety of functions, including several chemoreceptive functions, (Berryman, 1974 and Lubow, 1968). Canine chemoreception is generally excellent for a wide variety of stimuli although dogs are apparently not as sensitive as pigs, (S. R. I., 1974). An example of canine sensitivity is an absolute threshold of about 20 parts per billion for ethylene glycol dinitrate (a common explosive odorant). This threshold level is comparable with electronic sniffers, however the dog has the advantage of being able to respond to complex combinations of odors such as the scent of an individual human.

The olfactory abilities of dogs have been utilized for tracking moving objects and detecting special marker scents and natural odors from squalene, tobacco, drugs, explosives and human corpses, (Lubow, 1968). Particular breeds are better than others at such tasks; several relatively good breeds are listed in Table A.3 (Lubow, 1968 and McCartney, 1968). Other factors also effect olfactory thresholds. Such factors as age of stimulus and degree of concealment, odor preferences inherent in canines and ambient conditions at the detection site all effect the absolute threshold of sensitivity.

One way to enhance a dog's olfactory ability is to administer minute doses of the stimulus compound orally before the olfactory stimulation, (Moulton, 1974).

A.3.6 Other Chemoreceptive Capabilities

Listed below are animal groups with less potential of systems applications. Lower invertebrates including bacteria, protists and flatworms have been shown to respond to a variety of chemical stimuli, (Collias, 1980). Marine invertebrates, for example, coelenterates (Grant and Mackie, 1974 and Gesteland, 1971), starfish and clams (Droscher, 1969) utilize sensitive chemoreception to detect prey, avoid predators, locate sites for settlement and find mates. Marine arthropods, i.e., crabs and lobsters utilize similar sensitivities for the same basic functions. Reptiles and amphibians have generally poor chemoreception with the exception of snapping and green turtles which have been little studied, but behavioral observations indicate a good sense of olfaction. Finally, humans although poor chemoreceptors have been included in Table A.3 for comparison.

Table A.3 Parameters of Chemoreceptive Capabilities in Selected Animal Groups

GROUP	STIMULUS	THRESHOLD SENSITIVITY	RELATIVE SENSITIVITY	SPECIFICITY	DIRECTIONALITY	TYPE OF CHEMORECEPTOR
Bacteria	many compounds possible esp. if select for sensitivity e.g. propyl-glycol di-nitrate (rocket fuel)	usually good 1 p.p.m (18)		low		common chemical sense photoemmission indicator
Paramecium (6)	NaCl NaOH and other chemicals (esp. acids)	.1% .05%		low, but can distinguish bacterial types	yes, concentrate in weak acids	common chemical sense in oral groove
Flatworms e.g. Planaria (6)	-food odors - A.acide glutamine & Lysine - harmful chemicals	5×10^{-6}M		low	yes, chemotaxis to A.acids	common chemical sense in auracles
Coelenterata	Food - A.acids CO_2 - Amines & dipeptides	low			yes to both positive and harmful stimuli	crude contact chemoreceptors
Insect (17) general (19)	Pheromones ie. sex attractant molecules	extremely low thresholds-best of all animals	also very good	essentially complete specificity	highly directional	multiple specialized olfactory receptors
e.g. silkworm with Bombyx mori (17)	sex pheromone of female	males responds to a few molecules	excellent	complete (essentially)	excellent	specialized antennal receptors
Bees (17) (38)	several pheromones w/ different functions & characteristics like general pheromones above. e.g. ISO amyl acetate the alarm pheromone			high	good	antennal olfactory receptors
	CO_2		.03-.5%	essentially complete		specialized antennal
	H_2O		0.0-2.%	essentially complete		specialized antennal

Table A.3 continued

GROUP	STIMULUS	THRESHOLD SENSITIVITY	RELATIVE SENSATIVITY	SPECIFICITY	DIRECTIONALITY	TYPE OF CHEMORECEPTOR
Bees (cont)	Pharmacological compounds 30	$1.6\text{X}10^{-8}\text{M}$ for several compounds		medium to low		isolated abdomen contact chemoreceptors
	Propionic acid	$4.3\text{X}10^{11}\text{mol/cm}^3$				olfactory antennal receptors
	Butyric acid	$1.1\text{X}10^{11}\text{mol/cm}^3$				
	Methyl anthranilate	$1.9\text{X}10^{9}\text{mol/cm}^3$				
	Alpha iodine	$1.5\text{X}10^{10}\text{mol/cm}^3$				
	Phenyl propyl alcohol	$2.2\text{X}10^{9}\text{mol/cm}^3$	←(flower smell)			
	Eugenol	$2.0\text{X}10^{10}\text{mol/cm}^3$				
	sugars sucrose nectar sugars	1/10 man's sensitivity better than man				contact chemoreceptors
Ants 17	Pheromones	low	excellent	low	excellent	antennal
	CO_2		.04-.05%	excellent		specialized antennal
Blow fly 6 41 7	carrion, mercaptors, amines, hexanol, etc. e.g. sugar	.0018M	good	moderate		leg contact chemoreceptors
Mosquito	CO_2		.04-.05%	excellent	excellent	specialized receptors
Beetles and	Pheromones CIS-7-dodecenyl acetate	low	good	excellent	excellent	specialized olfactory antennal
Termites	Terpinolene					
Starfish 12	smell of clam	4in buried in sand			yes	tube feet chemoreceptors

Table A.3 continued

GROUP	STIMULUS	THRESHOLD SENSITIVITY	RELATIVE SENSITIVITY	SPECIFICITY	DIRECTIONALITY	TYPE OF CHEMORECEPTOR
Molluscs (12) Snail Nassarius	Human Blood plasma Oyster homogenate (glycoproteins)	2×10^{-9}M 2×10^{-10}M		Low	Yes	
Bivalves Pectin & Lima	Starfish odor	Slightest touch by starfish		Low		Contact chemoreceptors
Octopus (34)	Sucrose Hcl quinine	All 100 times better than gustation in man		Moderate		Contact Chemoreceptors in suckers
Sharks, Skates and Rays (11) (15) (21) (31)	Phenacyl chloride, a visual irritant	.005 ppm. effective			Highly	Olfaction
	Aplysia, cuviers gland of sea cucumber, & flat fish secretions	← other irritants		Good		Gustation
	L-serine (human sweat)	1 ppm.		Good	Yes	Common chem. sense
	Fish Extracts 14	$\sim 10^{-4}$ ppm.	Good	Poor	Yes	Olfaction
	Many compounds, especially food-related	1 ppm. range			High	Olfaction
Fishes Salmon	Morpholine	1 ppm. billion	Good	Very high-also to odor combinations	Excellent	Olfactory
Minnows (39) & (12)	Eugenol	1 pt. in 1.7×10^7				Olfactory
	Phenylethyl alcohol	1 pt. in 2.3×10^7				Olfactory
	Sweet: Raffinose	1/250,000 Moles/liter				
	Sweet: Sucrose	1/82,000 M (900 X Man)				
	Sweet: Lactose	1/2,560 M (160 X Man)				
	Sweet: Glucose	1/20,000 M (1575 X Man)				
	Sweet: Galactose	1/5,000 M (>500 X Man)				
	Sweet: Fructose	1/60,000 M (2,500 X Man)				

Table A.3 continued

GROUP	STIMULUS	THRESHOLD SENSITIVITY	RELATIVE SENSITIVITY	SPECIFICITY	DIRECTIONALITY	TYPE OF CHEMORECEPTOR
	Sweet: Arabinose	1/15,000M (1,100 X Man)				
	Sweet: Saccharin	1/1.5 X 10^6 M (164 X Man)				
	Bitter-quinine hydrochloride	1/2.4 X10^7M (24 X Man)				
	Salty-NaCl	1/20,000 M (205 X Man)				
	Sour-Acetic acid	1/205,000 M (164 X Man)				
Eels 22	B-phenylethyl alcohol	1 pt. in 3 X 10^{-8}pts. H_2O				Olfactory
	Citral, eugenol ionine, methanol,	Very Low		High specitivity at low thresholds	Probably	Olfactory
Reptiles Snapping turtle & Green turtle	Food Odors and also migratorial cues	Low but unknown			Probably excellent but untested	Olfactory
Birds 27 28 pigeon 33 (Italian best)	Amyl acetate Methyl methacrylate Salicylate Octonol Pyridine Trimethyl pentane	Lowest is $\approx 10^{-8}$ to 10^{-10} moles/ml.			Probably Good	Olfactory
Procellariiformes i.e. sea birds 3 37 36	Oily substances e.g. fish extracts & musk gland oils	Low thresholds, attracted to bacon fat from >20 miles			Excellent	Olfactory
Kiwi	Earthworm odors	Low(buried worms)		High	Locally good	Olfactory
Oilbird	Spicy & aromatic smells	Apparently man-like			Good	Olfactory
Grebe	Unknown, but based on anatomy		Should be highly sensitive			Olfactory
Honeyguide	Honey & wax	Low (behavioral influence)		High	Good	Olfactory

Table A.3 continued

GROUP	STIMULUS	THRESHOLD SENSITIVITY	RELATIVE SENSITIVITY	SPECIFICITY	DIRECTIONALITY	TYPE OF CHEMORECEPTOR
Turkey vulture	Ethyl mercaptan	Low		Responds to a group of odors from carrion	Good	Olfactory
Mammals general	Sensitive to biologically relevant compounds	Many sensitivities in the ppm range			Often highly directional	Olfactory & gustatory
Fox	Seagull eggs or seagull chicks	4" deep-9' detection eggs 2" deep w/in 20"		High	Locally	Olfactory
Pig (Red duroc)	Truffles & buried objects	Extremely low		High	Locally	Olfactory
Deer, ferret [40] Pig, Javelina [32] Cyote, cat, fox, racoon, skunk, civet coatamundi	Explosive odors e.g. C-4, Comp B, TNT, Tetryl, PETN & ROX	Pig-12" depth detection. Fox, cyote, ferret, skunk coatamundi, javelina & racoon-6" depth Dogs maximum 6" for best breeds		High to moderate		Olfactory
Dogs [20] [4]	Ethel glycol dinitrate	20 pp billion	Good	Good	Locally	Olfactory
	Iso-amyl alcohol	$1/10^7$ (dilution ratio)				
	Pentyl Acetate	1 molecule/10^{10} molecules				
Best breeds are	Benzaldehyde	$1/10^6$				
Rhodesian Ridgeback	Hexchloroethane	$1/10^9$				
Wimeraner mix.	Butyl mercaptan	1/10"				
Rabbit hound mix. Beagle mix. Basenji	Alpha ionine [25]	4.5×10^5 molecules/m^3 (5000-10000X Man)				
Shetland Sheepdog Alsatians [22]	Many other odors e.g., coffee, tobacco, drugs, humans	Low threshold often 1 ppm		High specificity	Excellent	Olfactory

Table A.3 continued

GROUP	STIMULUS	THRESHOLD SENSITIVITY	RELATIVE SENSITIVITY	SPECIFICITY	DIRECTIONALITY	TYPE OF CHEMORECEPTOR
Humans	Propionic acid	4.2×10^{11} molecules/cm^3				Olfactory
	Butyric acid	7×10^{9} molecules/cm^3	Foor	Poor	Poor sometimes Moderate	
	Methyl anthra-nylate	2.5×10^{10} molecules/cm^3				
	Alpha ionine	10^{8}-10^{9} molecules/cm^3				
	Phenyl propyl alcohol	6.5×10^{9} molecules/cm^3				
	Eugenol	8.5×10^{11} molecules/cm^3				
	Musk	5×10^{-5}ppm.				
	Sweet-sucrose saccharin	.1-.02 molecules/liter 3×10^{-4} M	20% 59 100% change in concentra-tion detectable	Several thousand discernable tastes	None	Gustation
	Sour- HCl	10^{-3}-10^{-4} M				
	Bitter-Quinine sulfate	10^{-6}-10^{-7} molesules/liter				
	Salt-NaCl	.03 to 01 M				

A.4 AUDITORY CAPABILITIES IN SELECTED ANIMAL GROUPS

Audition and the lateral line facilitate the perception of sound. Sound here is defined generally as pressure waves transmitted through a given medium with a characteristic velocity. Sound travels at approximately 350m/sec in air and about four times as fast in water. The body of an animal is essentially liquid and therefore audition of airborne sound required the evolution of various mechanisms for impedance matching between air and water. Audition under water is impedance matched, but only a few organisms with special adaptations have achieved frequency and intensity ranges comparable to those of terrestrial species.

Closely related to audition is lateral line sensitivity. This is the perception of low frequency vibrations in water within the nearfield (approximately 300m maximum). This sensitivity ranges from a few to a few hundred Hz. and is mediated by the lateral line organs.

There exists a gradient of anatomical structures for audition and a corresponding gradient of auditory functions. Distinctions between audition, lateral line perception, substrate vibration sensitivity, and tactile sensitivity are often vague but, for simplicity, will be reviewed in terms of human perception. Thus, tactile sensitivity and echolocation, though intimately related to audition, will be reviewed in other sections.

The auditory capabilities of humans will be briefly reviewed for comparative purposes. The frequency range audible to man is from 20 Hz to 20 KHz, but actually few humans hear the very high frequencies. Man is typically limited to 16 KHz. Amplitude or intensity of sound can be measured in decibels (dB) and is called sound pressure level. The dB is a relative measure, i.e., it measures the difference between two levels of sound, and thus, any dB measurement must be accompanied by a reference level or it is meaningless. The dB is referenced internationally as a sound energy level of .0002 dynes/cm^2 in air. This standard will be used throughout this review unless

otherwise noted. With this standard, men can hear sounds with an intensity range of 0 to 140 dB. The corresponding range of acoustic energy in sound varies 7 or 8 orders of magnitude, a 20 dB change corresponds to about ten times the acoustic energy. The lowest thresholds for human hearing occur between 1 and 4 KHz. Displacement of the eardrum at these thresholds is only a few angstroms, ($1 \mathring{A} = 1 \times 10^{-8}$cm). Maximal sensitivity to a change in frequency is 0.3% and to a change of intensity is .5 dB. Man has excellent audition by the standards of the animal kingdom, but many animals have surpassed our frequency range into what we subjectively call the infrasonic (frequencies below human perception) and ultrasonic (above human perception). Table A.4 summarizes data on parameters of audition in selected animal groups Several of these groups which show potential usefulness are reviewed separately below.

A.4.1 Birds (Aves)

Birds generally have good audition. Absolute threshold sound pressure levels are similar to man in the more sensitive birds. However, the frequency range of audible stimuli is usually more limited than in man and typically extends from 0.05 KHz. to 15 KHz. Pitch discrimination is also close to man in birds with good hearing (e.g., songbirds and parrots) and due to altered avian cochlear physiology, temporal discrimination is often far better. There is also a general trend of decreasing size paralleling increasing sensitivity and frequency range, for example, small songbirds generally hear soft, high pitched sounds better than larger birds.

Pigeons are only capable of distinguishing a 5-6% change in frequency, which is poor frequency discrimination with respect to humans, other birds, and even fish (Schwartzkopff, 1955). However, homing pigeons are sensitive in the infrasonic frequency range and have been proposed to utilize such sounds in homing. (Natural infrasonic stimuli include ocean breakers and wind blowing over mountain passes at great distances.) The upper frequency limit in pigeons is only about 12 KHz, and absolute sensitivity is best from 1500-2000 Hz, corresponding to the modal center of the pigeons' voice frequency. Temporal resolution, as in many birds, is quite good.

Owls possess exceptional auditory capabilities which were apparently evolved as an adaptation to a life of nocturnal hunting. The frequency range of sensitivity is similar to an acute human, but absolute thresholds for frequencies above 10 KHz are extremely low. Barn owls, e.g., Tyto Alba (Welty, 1975), can locate prey in complete darkness with a deviation of only 1° by utilizing extremely sensitive and accurate three-dimensional localization of the low intensity, high frequency sounds the prey produce. Such localization is facilitated by several adaptations, including: facial disks of feathers directing sound toward the ears, silent flight achieved by altered feather structure, asymmetric ears which provide less ambiguity in localization, and a wide head increasing temporal differences between the ears. These adapatations allow the comparison of loudness, timing and phase of auditory stimuli necessary for accurate localization.

A.4.2 Mammals (Eutheria)

The mammalian ear differs from other vertebrates in several significant respects. An external ear or pinna is present and performs several functions. It collects sound, aids in impedance matching at the air-liquid interface, and helps localize sounds by differential frequency delays that result as a consequence of its complex shape. In addition, only mammals have a three-bone middle ear mechanism which performs the balance of the necessary impedance matching (Henson, 1975). Also, the mammalian cochlea is long and coiled and thus has more sensory cells than many other animals. Generally, there is a trend indicating that the more recently evolved the vertebrate organism, the greater are its dynamic range and intensity discrimination capabilities (Wever, 1975).

Despite great interest in mammalian audition, little precise information is available and most work has been done with a few standard lab species and primates. The frequency range of many mammals extends beyond human limits, but threshold intensities are rarely significantly better because apparently many mammals have evolved near the physiological limits of audition.

Although data are not available on most species, by simple behavioral inferences, we can assume that most mammals have hearing similar to man, but often extending into frequencies beyond human sensitiivty. The reference by R. L. Francis, 1975, contains a good systematically organized bibliography on how hearing thresholds have been determined in different mammalian groups.

Rodents are sensitive to an extremely broad frequency range. Some have measured frequency ranges from 0.1 KHz to 100 KHz. Absolute threshold sensitivity is bimodal at 20 KHz and 50-70 KHz and has a value of 10 to 20 dB S.P.L. (Sales, 1975). Thus, rodent threshold data are slightly less sensitive than humans in their optimum frequency range but compensate with a broadened frequency range. Temporal discrimination of sounds is rapid. Rapid, sensitive, high frequency hearing is apparently useful to rodents whose lifestyle is visually limited since many forms are nocturnal and burrowing. Some rodents have even been reported to utilize the echoes of their own "scuffling" noises to echolocate in darkness.

The small echolocating bats (Microchiroptera) are sensitive to an even broader frequency range. Microchiropterans can hear frequencies from 1 KHz to 150 KHz with extremely fast recovery time. This quick recovery allows discrimination of up to 400 sound pulses/sec. Absolute thresholds are about 10-20 dB S.P.L. in the optimum frequency range which is variable, e.g., for Plecotus, it is 15-35 KHz and for Myotis, it is from 55 to 65 KHz (Novick, 1958 and Sales, 1975). Thus, some auditory parallels are observable in bats and rodents. More information will be given on Microchiropteran bats in Section A.5.

Dogs (Canidae) have excellent hearing. In general, predator-prey coevolution has resulted in many animal associations whose senses are highly tuned to detect one another. Thus, domestic dogs have evolved the ability to hear frequencies over 25 KHz with low thresholds throughout their entire frequency range. Cats have responded to similar evolutionary pressures with an even wider frequency range (Neff, 1975).

The final animal group of significance with respect to audition are the toothed whales (Cetacea). Echolocating cetaceans have a broad frequency range, typically from 0.07 KHz to 150 KHz. Absolute threshold intensity is good. For example, in *Tursiops truncatus*, it is 60 dB re: 1μ pa at 50 KHz (Johnson, 1968). Temporal resolution is so fast that porpoises can discriminate sounds separated by microseconds. These abilities are related to echolocation which will be discussed more fully in Section A.5. However, passive audition is apparently excellent; a nonecholocating and blindfolded dolphin can accurately locate and follow small fish (Diercks et.al., 1971). Finally, it is important to note that the baleen whales (nonecholocators) are capable of producing and hearing extremely intense low frequency sounds over long distances.

A.4.3 Other Auditory Capabilities

Listed below are other animal auditory capabilities that deserve mention but have little apparent feasibility for system applications.

Many invertebrates have a crude sensitivity to vibration, but only in insects do discriminative "ears" exist. Insect frequency range can extend from .001 KHz to 240 KHz and although threshold intensity can be as low as OdB S.P.L., higher thresholds are more common. Frequency discrimination is apparently rare, having been established only in moths and crickets. Auditory organs come in a variety of types and often have evolved with calling and "chirping." The most outstanding examples of insect audition have evolved as adaptations to avoid predation by the echolocating bats (Adams, 1971; Payne, 1966; and Roder, 1972).

The sharks, skates, and rays (Elasmobranchii) also have noteworthy audition. Near field sounds are sensed by the lateral line system while far field sounds are sensed by otoliths (ears). Frequency sensitivity ranges from the infrasonic to a few thousand Hz (Hodgson and Mathewson, 1978) and absolute thresholds are 10^{-3} dynes/cm^2 or higher (Henson, 1975). The remarkable thing about shark audition is its high degree of directionality and the attractivensss of pulsed sounds under 800 Hz (Nelson, 1963 and Wisby, et.al., 1964).

Table A.4 Parameters of Audition in Selected Animal Groups

GROUP	FREQUENCY RANGE	THRESHOLDS AND THRESHOLD FREQUENCIES	TEMPORAL DISCRIMINATION	FREQUENCY DISCRIMINATION
Insects (10)				
Moth & Butterfly Group	1 Hz - 240 KHz	0 dB - 100 dB at variable frequencies		Rare and Crude
Noctuid Moths (17) (14) (1)	20 Hz - 60 KHz	40 - 46 dB (same range)	.1 msec pulses	None
Hawk Moths (1) (16)	30 - 70 KHz	0.02 - 1 nm displacement		None
Locusts (6)	2 - 100 KHz	55 dB at 4-7 KHz 35 dB at 12-30 KHz	400 clicks/sec	Rare and Crude
Katydid	100 Hz - 120 KHz	30-40 dB at 7-60 KHz		None
Mosquito	150 - 550 Hz	0 dB at 380 Hz		None
Lacewings	13 - 120 KHz	60 dB at 40-50 Hz	1 msec. and resolves 150 sec.	None
Sharks, Skates Rays (5) (8) (7)	1 Hz - few thousand hz	.001 $dyne/cm^2$ at several hundred Hz		Moderate
Lateral Line	1 Hz - 200 Hz (12)	Near field (<100m, only) high thresholds. Best from 25-60 Hz & highly directional.	Poor	Possible even under 10 Hz
Audition (23)	25 - less than 5KHz	0.001 $dyne/cm^2$ at a few Hz.		Poor (via behavior)
Fish (22) Osteichthyes w/out middle ear	500 - 1200 Hz	High thresholds		
w/middle ear e.g., minnow e.g., catfish	50Hz - 6 or 8 KHz 32 Hz - 6 KHz up to 18 KHz	-60 to -70dB (re: 1μ bar) thresholds ≈ 100 x man in acoustic energy		3.0%
Lateral Line	1 - 200 Hz	Near field - 25-50 Hz	Poor	
Amphibia (20) frogs, newts & salamanders	all types low freq/ i.e., up to a few thousand Hz	-20 dB (Re: 1 $dyne/cm^2$) at 400 & 1200 Hz. in <u>B. marinus</u>		

Table A.4 Continued

GROUP	FREQUENCY RANGE	THRESHOLD INTENSITY AND FREQUENCY	TEMPORAL DISCRIMINATION	FREQUENCY DISCRIMINATION
Reptiles (22)				
Snakes (2)	50 - 5 KHz	1 Å amplitude at 300 Hz or -30 dB re: 1 $dyne/cm^2$		
Lizards e.g., gecko	100 Hz - 10 KHz 100 Hz - 10 KHz	-40 to -60 dB (re:1 $dyne/cm^2$) -87 dB (re: 1 $dyne/cm^2$)		
Turtles	100 Hz - few thousand Hz	-60 to -70 dB (re:1 $dyne/cm^2$) at 200-700 Hz		
Crocodile	20Hz - 7 KHz	-65 dB (re: 1 $dyne/cm^2$) from 300-1500 Hz		
Birds (22) (21)				
Song Birds & Parrots	500-1500 Hz	1 X 10^{-4} $dynes/cm^2$ from 1 - 4 KHz	.6 to 2.5 msec. interval allows discrimination	0.3% - 0.7%
Pigeon (19)	infrasonic 10Hz → 12 Hz	most sensitive from 1800 - 2400 Hz	good	5.0 - 6.0% (Poor)
Owls	<100 Hz - 18 KHz	very low theshold w/ good localization > 10 KHz		
Budgerigar	40 - 14000 Hz	-70 dB (re: 1 $dyne/cm^2$) at 1700 & 3500 Hz	good	
Chaffinch	200 Hz - 29 KHz	Similar to man from 1-4 KHz	good	
Mammals (4)		Similar to man		
Dogs	? → 25 KHz			
Cats	? → 60 KHz or 100 KHz via electrophysiology	Thresholds lower than humans over entire range		
Rodents	100 Hz - 100 KHz	bimodal: 10-20 db (18) at 20 KHz & 50-70 KHz	Rapid	
Harbor Seal (22)	→ 160 KHz	12 KHz in air 32 KHz under water		
Bats (13)	1 ≥ 150 KHz	10-20 dB at 15-35 KHz (18) Plecotus; 55-65 KHz Myohs	400/sec.	
Echolocating Cetaceae (9)	70 Hz - 150 KHz	-60 dB (re. 1μ na) at 50 KHz (can passively track fish by their swimming sounds (3)	Can discriminate sounds separated by microseconds	
Chimpanzee	20 - 20 KHz ?	Slightly > humans - whole range		
Rhesus monkey	20 - 20 KHz ?	Like man but lower at 8 KHz		
Marmoset	20 - 20 KHz ?	Like man but lower at 7^{-20} KHz		
Human	20 - 20 KHz ?	0dB at 1-4 KHz ($2x10^{-5}\mu$ bar)		0.3%

A.5 ECHOLOCATION IN SELECTED ANIMAL GROUPS

Echolocation is common and highly developed in bats (suborder Microchiroptera) and toothed whales (Odontoceti). Other organisms also utilize echolocation with variable degrees of sophistication. Among such animals are various birds, a fish, shrews, and possibly rodents and pinnipeds (seals). Only cetacean echolocation is of certain immediate relevance to the Coast Guard and thus only the echolocation of toothed whales will be described in detail below. The other echolocators will be described more generally afterward.

A.5.1 Toothed Whales (Odontoceti)

The production of a focused high frequency beam of sound and sensitive directional hearing are the elements of echolocation with which toothed whales can discriminate the acoustic reflectivity of objects under water. Toothed whale echolocation will be reviewed by first describing echolocation capabilities, then pulse production, and finally, pulse reception.

A.5.1.1 Capabilities. Dolphins are capable, via echolocation, of determining the presence, location, size, shape, and even the composition of underwater objects. Examples showing the extent of each of these echolocation performance dimensions will be given below (see Table A.5 also). Range limitations, which ultimately limit all echolocation performance dimensions will also be noted. Much of the following information and many of the references cited were obtained from Animal Sonar Systems, Jersey Symposium, April, 1979, which provides a good recent review of Odontocete echolocation capabilities.

An example of the Atlantic Bottlenose dolphin's (*Tursiops truncatus*) ability to locate underwater objects is its ability when temporarily blindfolded, to detect and locate a floating object the size of a vitamin capsule across

a large enclosed tank (Johnson, 1967). Other examples of localization are provided by obstacle avoidance experiments (for a review, see Moore, 1979). Temporarily blinded Tursiops truncatus can swim iron pipe mazes without making contact (Norris, et.al., 1961) and can similarly avoid vertically strung triangular metal poles placed less than three meters apart (Kellog, 1958). Another dolphin, Phocoena phocoena, can avoid wires of copper, iron, and steel as small as .35mm in diameter (Busnel and Dziedzic, 1967) and another species, Inia geoffrensis, has also been shown to exhibit similar wire avoidance capabilities.

There are a variety of methods for measuring performance of echolocation in discriminating the size of objects. Tursiops truncatus has been the most studied species and has been found capable of detecting small size differences in: solid metal spheres (Norris, Evans, and Turner, 1967); solid cylinders (Evans, 1973), (Ayrapet'yants and Konstantinov, 1974); and planar targets, including circular disks and squares (Barta, unpubl.). Size discrimination abilities have been measured from a variety of distances using a variety of target shapes, sizes, and materials. The ability to detect the thickness of underwater objects has also been measured in a similar variety of experimental situations (i.e., planar targets of different thicknesses were studied (Evans and Powell, 1967); as were hollow cylinders (Hammer, 1978), (Titov, 1972); and circular disks (Evans and Powell, 1967)). This variety of measurements has yielded a corresponding variety of threshold data (Table A.5). Generally, size discrimination depends on closeness to the target, target size, and target material. Size discrimination thresholds of 5% - 10% are common. (This percentage difference corresponds to a variation of approximately 1 db in target strength, see Evans, 1973).

Echolocation performance on shape has also been tested using a variety of target shapes, materials, and distances. Results generally demonstrate that Tursiops truncatus can resolve small (a few percent) differences in target shapes, even if target orientations are altered within certain limits. These

echolocation performance experiments on shape have been done using: planar targets (Barta, unpubl.), (Bagdonas, Bel'kovich, and Krushinskaya, 1970), (Bel'kotich and Dubrovskiy, 1976); three dimensional pyramids (Bel'kovich, et.al, 1969); and cubes vs. cylinders (Murchison and Nachtigall, 1977), (Nachtigall, Murchison, and Au, 1978). Tursiops truncatus can resolve different planar shapes, two-dimensional from three-dimensional shapes, small proportional changes in a three-dimensional shape, horizontal from vertical cylinders, and cubes from cylinders of similar reflectivity, even in some altered orientations.

Echolocating dolphins can distinguish the material of many underwater objects. Evans and Powell showed in 1967 that Tursiops truncatus can distinguish copper, aluminum, and brass plates independent of the amount of target reflectivity. Much Russian research in this area has tested the ability of dolphins to discriminate between many materials, e.g., wood, plastic, glass, brass, ebonite, textolite, fluroplastic, lead, steel, duraluminum, wax, parrafin, rubber, and plexiglass. All of these discriminations can be made except for glass-aluminum (Hammer, 1978), steel-duraluminum, wax-rubber, and wax-parrafin. (For reviews, see Ayrapet'yants and Konstantinov, 1974, or Bel'kovich and Dubrovski, 1976.) Dolphins probably make these discriminations on the basis of the acoustic characteristics of the positive target rather than by comparisons (Hammer, 1978). Once again, target size and distance to the target are important factors in material recognition, but within these limits, most materials tested have been discriminable on the basis of echolocation alone.

Maximum detection range is another important dimension of echolocation. As an indicator of this ability, Tursiops truncatus can detect a three-inch diameter water-filled steel ball at distances of over 120 meters. In a shallow open water situation, a detection range for three types of steel spheres has been measured (Murchison, 1979 and 1980). A solid steel sphere 2.54 cm. in diameter can be detected up to 72.3 meters away. Another sphere made of hollow stainless steel filled with water and 7.62 cm. in diameter was detected

up to 76.6 meters. A third sphere was solid steel, 6.35 cm. in diameter, but tested close to the bottom to test the effect of bottom proximity on detection range. Results showed the detection range was cut from 74 meters to 70 meters by moving the target closer to the bottom. Field reports indicate that dolphins can detect very large reflective targets at greater distances, for example, the bubbly wake of a tuna purse siener is apparently detected at about 140 meters (Moore, 1979). Estimations of echolocation range on very large objects (e.g., schools of fish) indicate that echolocation may be useful at over 300 meters.

Range resolution, i.e., the ability to detect small differences in the distances to objects, has been tested (Murchison, 1980). The smallest range difference Tursiops truncatus can resolve using two 7.62 cm. diameter polyurethane foam spheres at about 1 meter is .9 cm. This range resolution threshold rises to 1.5 cm. at 3 meters distance, and 3 cm. at 7 meters. Thus, Tursiops truncatus can resolve small range differences, but this ability decreased with increasing distance to the targets.

Communicative capabilities of echolocation signals have been repeatedly proposed, but as yet are unsubstantiated beyond simple communication as found in other mammals (Bastian, 1967; Evans and Bastian, 1969). However, dolphins are capable of forming "constancy" as previously outlined for the pigeon.

Echolocation is apparently widespread in toothed whales and has been definitely established in seven species. The baleen whales (Mysteceti) do not have proven echolocation but have adapted to produce and receive low frequency sounds over hundreds of miles. Such sounds have been recorded from finback, blue and grey whales (Thompson and Cummings, 1969; Cummings and Thompson, 1971). These sounds are very loud (88 db re 1 bar at 1 meter for blue whale), very long (30 seconds), and range in frequency from .012 to .2 KHz.

A.5.1.2 Pulse Production. The mechanism of echolocation will be briefly outlined below, starting with sound production. Sound production is accomplished in the nasal region and entails several adapations to ensure a narrow and highly directional frontal beam of high frequency sound (Evans and Maderson, 1973). However, the mechanism of sound production and directionality still remains unclear. Although strict distinctions cannot be made, there are two functional classes of sounds produced. The first class of sounds are clicks used primarily for echolocation, while the second class of sounds includes a variety of whistles, squeals, and barks used primarily for communication.

Echolocation clicks are brief, broad band pulses which are acoustically complex and repeated rapidly such that their cumulative audible effect is a rasping or grating sound. These pulses have species specific variations in amplitude, bandwidth, and frequencies of peak energy. Echolocation pulses have been classified on the basis of these characteristics with partial success (Evans, 1973). The repetition rate of pulses is also species specific and rates of up to 1920 clicks/sec. have been reported (Norris, et.al., 1972). Finally, there is evidence that individual animals can vary the length, repetition rate, frequency of highest energy, and direction of echolocation pulses in order to maximize the efficiency of the echolocation task at hand.

Of the communication sounds used by toothed whales, the whistles are best characterized. They are, generally, pure tone frequency modulated pulses of extended length, containing frequencies from 2 KHz to 20 KHz. Usually, they are given during times of general excitement or are used as signals for warning, distress, mating, calling young, etc. The structure of whistles can be complex and has been hypothesized to carry intelligent information, but there is little evidence supporting this idea.

A.5.1.3 Pulse Reception. Sound is propagated quickly in water, and there is a relatively small density change as sound enters an aquatic animal's

body. Thus, sound reception in aquatic organisms may, on theoretical grounds, be excellent. This is especially true in toothed whales in which many adaptations have created a highly directional and sensitive auditory mechanism which functions over a wide frequency range. Specific data on cetacean auditory capabilities were given in Section A.4. The combination of this sensitive, directional (Bullock, et.al., 1968), high frequency hearing with he sound production capabilities previously mentioned has created an acoustic sense which can function under conditions which render vision useless.

A.5.2 Bats and Other Echolocators

There are two suborders of Chiroptera (bats), the Megachiroptera and Microchiroptera. Megachiropterans are large, have good eyesight, and eat fruits. Only one megachiropteran genus (Rousetlus) echolocates. It produces broadband echolocation sounds by tongue clicking, a unique characteristic among bats. Many microchiropterans use echolocation for a variety of functions. Microchiropterans are nocturnal, small and maneuverable, and their echolocation allows determination of the direction, distance, velocity, size, shape, and nature of objects in the air. Accurate directionality is exemplified by the capture of 1mm. mosquitos commonly accomplished by many species. An example of distance discrimination is the ability of Eptesicus to discriminate 58.5 cm. from 60 cm. distances. Examples of the threshold of discrimination are bats of the family Vespertilionidae, detecting vertically strung .5mm diameter wires at 2 meters by echolocation, and horseshoe bats similarly avoiding .08mm wires in complete darkness (Airapet'yants and Konstantinov, 1973). Another noteworthy example is Noctilio leporinus which can catch fish near the surface of ponds possibly utilizing echolocation at very short range under water (Bloedel, 1955). Bats are also capable of overcoming large amounts of ambient noise as typically occurs when they discriminate small insects among other echolocating bats or near large and reflective background objects.

Echolocation pulses consist of brief, intense chirps, most commonly produced in the larynx, ranging in frequency from 12 KHz to as high as 260 KHz (Griffin, 1958). High output frequencies allow reflection off of small objects and therefore, increased discrimination, but concurrently decrease the effective range of the system. The design and repetition rate of output sound pulses are altered during cruising, pursuit, landing and obstacle evasion and also vary with the family and species, as is true also in the toothed whales.

Reception of echolocation signals is facilitated by sensitivity to frequencies from 1 KHz to over 150 KHz and excellent recovery time and temporal resolution capabilities.

The oil bird (Steatornis capripensis) and two species of the swift genus Collocalia use echolocation to allow obstacle evasion and orientation in the complete darkness of caves in which they nest. Bird echolocation is crude relative to dolphins and bats. Longer pulses (1-6 msec.) of lower frequency sound (4-7 KHz) are repeated relatively slowly (5-10/sec.) in order to avoid large obstacles (Novick, 1959; Arapet'yants and Konstantinov, 1973).

Rodents perceive ultrasounds and some have been demonstrated to employ at least a crude echolocation sense to orient in darkness (Rosenzwieg, et.al., 1955; Riley and Rosenzwieg, 1957). Insectivores, i.e., shrews and the Tenrec, have also been shown to possess echolocation. Pulses of 5-30 msec. duration with frequencies from 30 to 60 KHz and intensity of up to .14 dyne/cm^2 at 7 cm. are used for low resolution and highly local object detection. Seals and sea lions have also been hypothesized as echolocators (Poulter, 1966), but little evidence for this has been produced. Even a sea catfish, Arius felis, has been found to possess a rudimentary acoustic orientation ability (Tavolga, 1977).

Overall, the range of natural echolocation systems is relatively short relative to man-made radars and sonars, but resolution is suprisingly good. Animal systems also resist interference by noise very well and can be trained to indicate the results of an echolocation task with an appropriate response.

Table A.5 Discrimination Capabilities and Sound Output Characteristics of Echolocating Animal Groups.

GROUP	MINIMUM DETECTABLE WIRE SIZE	SIZE DISCRIMINATION	SHAPE DISCRIMINATION	COMPOSITION DISCRIMINATION	PULSE-ECHO OVERLAP	PULSE DURATION	PULSE FREQUENCY RANGE	PULSE FREQUENCY STRUCTURE	PULSE INTENSITY	PULSE RATE	ECHOLOCATION RANGE
	Discrimination Capabilities				Sound Output Characteristics						
Bats 27 5 Vespertilionoidea 14 44	0.2mm at at 2m distance	10	2nd and 3rd geometric shapes and small Δ's therein	Aluminum Plexiglass Plastic Metal, Wood	None	.5msec-4msec	12-150 KHz (to 260 KHz reported)	CF & FM	1-200 dynes/cm^2 5cm from mouth; 1000 dynes/cm^2 in M. tristis	from 10 to 200sec^{-1}	[illegible]
Rhinolophoidea (horseshoe bats) 5 44	0.08mm	10	2nd and 3rd geometric shapes and small Δ's therein	Aluminum Plexiglass Plastic Metal, Wood	Present	20-200msec. Avg. 100msec		CF only	600-1500 dynes/cm^2 at 5 cm or; 200 dynes/cm^2 at 15 cm	15-50/sec	[illegible]
Noctilionidae (fish-eating bats)					Variable	1-5msec.	20-60 KHz to over 120 KHz	CF & FM	50-60dynes/cm^2 at 50 cm (very high)	5-[illegible]/sec	
Phyllostomatoidea (leaf-nosed bats)	0.17mm	10.	2nd and 3rd geometric shapes and small Δ's therein	Aluminum Plexiglass Plastic Metal, Wood	None	1-2msec.	70-130KHz	FM	1-10 dynes/cm^2 at few cm. (very low)		~20 cm (through [illegible])
Desmodontidae (Vampire bats)					None	1-2msec.	25-90 KHz	FM	(very low)		[illegible]
Rousettus (fruit-eating bat)						3-6msec.	6.5-100KHz and complex via tongue	complex & disorganized	high	4-5/sec	

NOTE: All species reject noise well and therefore aren't easily "jammed."[1]
All miorochiroptera have high temporal resolution.

Cetacean Echolocation Capabilities on Size, Shape and Material
(taken from Nachtigall, 1980)

Table A.5 Size Discrimination

TARGET		VARYING TARGET SIZE (cm)		SIZE DIMEN.	METHOD	THRESH-OLD	CORR.	MIN. DIST.	SPECIES	LIT. SOURCE
SHAPE	MATERIAL	POS.	NEG.							
Solid	Nickel-	6.35	5.72	Dia.	2 Alt.	.63 cm	77	0	Tursiops	Turner &
Spheres	Steel		5.40		Force		90		Truncatus	Norris
			5.08		Choice		93			(1966)
			4.76				98			
			4.45				100			
			4.13				100			
			3.97				100			
			3.81				100			
			3.18				100			
Wires	Iron	-	.35	Dia.	Obstacle		98.9			
	Copper		.15		Avoidance		98.9	0	Phocaena	Busnel,
	and		.075				94.7		Phocaena	Dziedzic
	Steel		.05				90.9			& Anderson
			.035			.035 cm	78.9			(1964)
			.02				46			Busnel &
										Dziedzic
										(1967)
	Nylon		.15				72.5			

Table A.5 (Cont'd). Size Discrimination

TARGET		VARYING TARGET SIZE (cm)		SIZE DIMEN.	METHOD	THRESH-OLD	CORR.	MIN. DIST.	SPECIES	LIT. SOURCE
SHAPE	MATERIAL	POS.	NEG.							
Solid Cylinders H=17.78 cm	Chloro-prene (Dc-100)	1.64	2.07	Dia. & dB -18dB	2 Alt. Forced Choice	.43 cm	85	.77 m	Tursiops Truncatus	Evans (1973)
			2.62	-17dB			94			
			3.28	-16dB			89			
			4.16	-15dB			96			
			5.20	-14dB			90			
		1.64	2.07	-18dB		.98 cm	70	.77 m	Inia Geof-frenis	
			2.62	-17dB			77			
			3.28	-16dB			89			
			4.16	-15dB			90			
			5.20	-14dB			90			
Circular Disks	Neoprene (Cell-tite) Back with Aluminum	15.2	25.0	Dia.	2 Alt. Force Choice	.9 cm	38.3	.7 m	Tursiops Truncatus	Barta & Evans (Unpub-lished Manuscript)
			20.0				98.5			
			18.0				97			
			17.2				94.1			
			16.1				74.8			
			15.7				57.5			
			15.2				50.7			

Table A.5 (Cont'd). Size Discrimination

TARGET		VARYING TARGET SIZE (cm)		SIZE DIMEN.	METHOD	THRESH-OLD	CORR.	MIN. DIST.	SPECIES	LIT. SOURCE
SHAPE	MATERIAL	POS.	NEG.							
Circular Disks D=20 cm	Copper	.22	.16 .27 .32 .64	Thickness	2 Alt. Forced Choice	.10 cm	50 60 75 90	.7 m	Tursiops Truncatus	Evans & Powell (1967)
Hollow Cylinders	Aluminum	OD= 7.62 .95	.31 .63 1.27 1.59	Wall Thickness	2 Alt. Successive Probe	-	100 100 100 100	6 m 16 m	Tursiops Truncatus	Hammer (1978)
H=17.78 cm		OD= 3.18 .64	.32 .48 .80 .96				100 100 100 100			

Table A.5 Shape Discrimination

TARGET SHAPE & MATERIAL: POSITIVE	TARGET SHAPE & MATERIAL: NEGATIVE	TARGET SIZE* CM: POSITIVE	TARGET SIZE* CM: NEGATIVE	METHOD	DISTANCE TO TARGET	PERCENT CORRECT	SPECIES	SOURCE
Circular Neoprene Disks	Flat Squares	182 cm^2	428 cm^2	2 Alt Forced Choice	.7 m	100	Tursiops Truncatus	Barta & Evans (Unpub-lished Manu-script)
			269 cm^2			98.6		
			182 cm^2			93.1		
			87 cm^2			100		
Circular Neoprene Disks	Flat Triangles	182 cm^2	346 cm^2			97.9		
			187 cm^2			92.3		
			48 cm^2			100		
	Circular Disks	182 cm^2	182 cm^2			49.6		
Solid Styrofoam Cylinders (Straight Up)	Solid Styrofoam Cubes (Flat Face Forward)	H 4 cm	H 4 cm	2 Alt Forced Choice	2 m		Tursiops Truncatus	Nachtigall, Murchison, And Au (This Volume)
		D 4 cm	D 4 cm			75		
			H 5 cm					
			D 5 cm			94		
			H 6 cm					
			D 6 cm			91		
		H 5 cm	H 4 cm					
		D 5 cm	D 4 cm			87		
			H 5 cm					
			D 5 cm			87		
			H 6 cm					
			D 6 cm			98		
		H 6 cm	H 4 cm					

Table A.5 (Cont'd). Shape Discrimination

TARGET SHAPE & MATERIAL		TARGET SIZE CM		METHOD	DISTANCE TO TARGET	PERCENT CORRECT	SPECIES	SOURCE
POSITIVE	NEGATIVE	POSITIVE	NEGATIVE					
		D 6 cm	D 4 cm		2 m	91		
			H 5 cm					
			D 5 cm			94		
			H 6 cm					
			D 6 cm			96		
Cylinders Straight Up	Cubes Edge Forward	All Sizes	All Sizes	2 Alt Forced Choice Probe		93		
Cylinders Layed Horizontal	Cubes Edge Forward	All Sizes	All Sizes	2 Alt Forced Choice Probe		71		
Cylinders Flat Top Forward	Cubes Flat Face Forward	All Sizes	All Sizes	2 Alt Forced Choice Probe		57		

Table A.5 Materials Discrimination

TARGET			METHOD	PERCENT CORRECT	MIN. DIST. TO TARGETS	SPECIES	SOURCE
SHAPE	MATERIAL & SIZE (CM)						
	POSITIVE	NEGATIVE					
Circular Disks	Copper	Aluminum	2 Alt Forced Choice		Ø	Tursiops Truncatus	Evans & Powell (1967)
	D-20 T.22	D-20 T.32		100			
		D-20 T.64		98			
		D-20 T.79		93			
		Brass					
		D-20 T.32		55			
		D-20 T.64		100			
Cylinders H-17.78 cm	Hollow Aluminum	Solid Coral Rock/ Epoxy Resin	2 Alt Successive Presenta-tions (Baseline)		6 m 16 m	Tursiops Truncatus	Hammer (1978) Experi-ment I
	D-3.81 WT-.64	D-3.81		100			
	D-7.62 WT-.95	D-7.62		100			
		D-3.81		100			
		D-7.62		100			
		Solid Aluminum	2 Alt. Successive Presenta-tions Probe				
		D-3.81		100			
		D-7.62		100			
		Hollow Aluminum					
		D-6.35 WT-.48		100			
		D-11.43 WT-.64		100			

Table A.5 (Cont'd). Materials Discrimination

TARGET			METHOD	PERCENT CORRECT	MIN. DIST. TO TARGETS	SPECIES	SOURCE
SHAPE	MATERIAL & SIZE (CM)						
	POSITIVE	NEGATIVE					
		Solid Coral Rock/Epoxy Resin D-11.43		100			
		Solid Chloroprene D-6.35		100			
		D-4.06		100			
		Polyvinyl-Chloride D-7.62 WT-.79		100			
Cylinders H-17.78 cm	Hollow Aluminum	Solid Coral Rock/Epoxy Resin	2 Alt Successive Presentations (Baseline)			Tursiops Truncatus	Hammer (1978) Experiment III
	D-3.81 WT-.32	D-3.81		100			
		D-7.62		100			
	D-7.62 WT-.40	D-3.81		100			
		D-7.62		100			
		Hollow Bronze	2 Alt Successive Presentations Probe				
		D-3.81 WT-.32		75	6 m*		
		D-3.81 WT-.32		37.5	16 m		
		D-7.62 WT-.40		100	6 m*		
		D-7.62 WT-.40		62.5	16 m		

Table A.5 (Cont'd). Materials Discrimination

TARGET			METHOD	PERCENT CORRECT	MIN. DIST. TO TARGETS	SPECIES	SOURCE
SHAPE	MATERIAL & SIZE (CM)						
	POSITIVE	NEGATIVE					
		Hollow Glass					
		D-3.81 WT-.32		Ø	6 m*		
		D-3.81 WT-.32		Ø	16 m		
		D-7.62 WT-.40		12.5	6 m*		
		D-7.62 WT-.40		12.5	16 m		
		Hollow Steel					
		D-3.81 WT-.32		87.5	6 m*		
		D-3.81 WT-.32		100	16 m		
		D-7.62 WT-.40		100	6 m*		
		D-7.62 WT-.40		100	16 m		

KEY:
D = Diameter
T = Thickness
WT = Wall Thickness
H = Height
* = 6 m data from the second series following the 16 meter data collection.

Table A.5 continued

Other Organisms

GROUP	PULSE DURATION	PULSE FREQUENCY RANGE	PULSE RATE	PULSE INTENSITY	ECHOLOCATION CAPABILITY
Birds 46 <u>Steatornis capripensis</u> (Trinidad Oil-bird)	1 msec.	7 KHz	In groups of 2-6 with 2.5msec. quiet intervals	Audible at 200 meters	Simple obstacle avoidance and visual backup system.
genus <u>Collocalia</u> 5 45	2-6 msec.	4-5 KHz fundamental w/overtones < 20 KHz	5-10/sec.		Obstacle avoidance in dark caves.
Shrews genus <u>Sorek</u> 25 26	5-35 msec.	30-60 KHz		.02-.14 $dynes/cm^{2-1}$ 7cm from mouth	Low resolution and highly localized.

Note: Rodents have been hypothesized as echolocators because of excellent high frequency hearing, but no solid evidence for this exists. Echolocation may occur by reception of echoes of randomly produced scratching and scuffling. Some behavioral evidence exists for this in voles and laboratory rats.

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GROUP	FREQUENCY RANGE	THRESHOLD
Housemouse	up to 100 KHz	10-20 dB at 20 KHz + 60 KHz (bimodal)
Guinea pig, Red backed vole	up to 50 KHz	
Golden Hamster	up to 23 KHz	

RODENT SOUND PRODUCTION

GROUP	FREQUENCY RANGE
Red backed vole	15.5 KHz
Housemouse and Field Mouse young	72-74 KHz

Note: The Sea catfish <u>Arius felis</u> is capable of rudimentary acoustic orientation.[28] Seals and Penguins are also suggested possibilities.

A.6 TACTILE SENSITIVITY IN SELECTED ANIMAL GROUPS

The tactile senses are potentially important because of their accessory role in a variety of important tasks animals may be required to perform. Therefore, tactile senses will be described here in general terms to give an idea of the relative tactile abilities of animals. Little quantitative data have been obtained on tactile sensitivities, partially due to difficulties in quantifying and standardizing stimuli for the wide variety of receptor types that exist. Examples of some organisms with exceptional tactile capabilities are given in Table A.6.

Three basic types of receptors and their appropriate stimuli are: cutaneous exteroreceptors which detect tactile information, usually by pressure or motion; interoreceptors which detect motion or mechanical changes in internal organs; and proprioceptors which detect the positions of muscles, tendons, and joints. These sensitivities have been studied in humans and a few vertebrate laboratory animals, but, unfortunately, have been little studied in invertebrates.

Despite the lack of precise data, it is known that invertebrates from the phylogenetic level of protezoans and higher show behavioral responses to minute tactile stimuli. Invertebrate groups with exceptional sensitivity are the jellyfish and anemonies, a few flatworms, nudibranchs, and protezoans; their tactile sensitivity being behaviorally indicated by the discharge of nematocysts. Echinoderms (starfish and sea urchins) and Mollusks (octopi, snails and squids) employ excellent tactile sensitivity associated with and indicated by their complex body movements. Among the Arthropods, there are also many examples of good tactile sensitivity such as Crustaceans (e.g., lobsters) and Arachinids (spiders). Insects possess a variety of tactile sensory appendages and are thus acutely sensitive to tactile changes in the near field. For example, honeybee behavior ranging from trancelike immobility to hive defense is partially dependent on the frequency of hive vibrations. Unique tactile receptors called subgenual organs exist in many insects and are sensitive to substratum vibrations with amplitudes 100 times smaller than the smallest detectable amplitudes in the human eardrum (Richard and Davies, 1977).

Tactile senses have been more thoroughly studied in vertebrates, especially humans. Generalizations about tactile sensitivity can be extended from man to other vertebrates (particularly mammals) on the basis of similarities in anatomy and behavior. There are, however, unique tactile sensitivities in each class of vertebrates, as is exemplified by substrate vibration sensitivity in salamanders and snakes (Smith, 1968; Hartline, 1971). The more common tactile receptor types will be described briefly below.

Internal tactile senses (interoreceptors and proprioceptors) detect the movement and status of internal organs, joint and tendon positions, and muscle position and tension. For an example, see Table A.6.

Cutaneous receptors (tactile receptors located in the skin) are varied in structure but can be divided into two functionally distinct categories: first, mechanoreceptors, which are concerned with perception of nondamaging mechanical disturbances, and second, nociceptors whichare concerned with perception of potentially damaging stimuli, i.e., pain. Pain has been studied in carnivores and primates and its presence in other vertebrate classes (excluding Elasmobranchii) can be assumed on the basis of behavior (Burgess and Pearl, 1973). Mechanoreceptors can be further subdivided into those occurring in hairless skin and those occurring in hairy skin. Mechanoreceptors occurring in hairless skin have been studied in humans, cats, racoons, and primates. They occur densely in the foot and toe pads of cats, the snout and palms of racoons and the hands and feet of primates. These pressure and movement sensitive mechanoreceptors are what is commonly labeled the "sense of touch." Such sensitivity is functionally similar in all organisms studied. Mechanoreceptors in hairy skin provide four types of tactile information: position of hairs, velocity of hair movement, direction of movement, and transient movements. Examples of mechanoreceptors in hairy skin are vibrassae, the long thick hairs on the nose, mouth and wrists of the forelimb of cats, the nose of rodents, the mouth of dogs, and the fingers of primates. Vibrasses (and sinus hairs) convey information about their position, velocity and direction. Similar information is detected by receptors occurring in and around the teeth and claws of cats (Burgess and Pearl, 1973).

In summary, although direct comparisons are difficult to make, tactile sensitivity is relatively good in invertebrates, even those very low on the phylogenetic scale. Among higher organisms, most vertebrates, especially mammals, are very similar to humans as far as is known. Finally, it is important to note that adaptation seems to be universal with respect to tactile senses. Rapid tactile adaptation allows the elimination of tactile "noise" so that the resolution of relatively small, but significantly different, stimuli is possible. However, this resolution is achieved at the cost of rapid loss of perception of all constant stimuli.

Table A.6 Tactile Sensitivities as Measured in Selected Animal Groups

ORGANISM	FREQUENCY	THRESHOLD
Coelenterata anemonies		Reflex to light touch & chemicals
Crusteceans, e.g., Lobster		Slight touch results in tail flip reflex
Snails and octopus 6		Circle vs. Cube & Grooved vs. Smooth objects. Sensitive to texture differences
Insects 3	1-5 KHz	0.01 to 10.0 Å substrate vibration
Reptiles - skink 2	300-700 Hz	54 dB (re: 2 x 10^{-5} dynes/cm^2)
snake	ear 50-500 Hz skin 500 > 1000 Hz	1 Å at 300 Hz (20 dB re: 1.0 Å p-p) } both better than man < 1000 Hz.
Mammals joint movement	at 10°/min	0.2° hip movement
pain receptors 1	multimodal receptors	at level of potential damage
mechanoreceptors transient sensitivity: vibrassae (in cats, primates, rodents, etc.)	few to few hundred Hz	e.g., 5-15M skin movement in cat is exceptionally detectable

A.7 ELECTRORECEPTION AND MAGNETIC FIELD SENSITIVITY IN SELECTED ANIMAL GROUPS

Organs for detecting electric and magnetic fields have evolved in a variety of animals from bacteria to birds. Electroreception can be conveniently divided on a functional basis into two categories, passive and active electroreception, (Bullock, 1974). Passive electroreception involves detection of electric fields produced by external sources as when a shark detects its prey via prey-produced electric fields, (Kalmijn, 1971). Active electroreception is more complex and occurs, like passive electroreception, in aquatic environments where vision plays a minor role. In an active electroreception system the organism not only perceives the electric field, but also produces the field it perceives. Such a fish produces a pulsating electric field with specialized electric organs and detects distortions in that electric field by specialized receptors. These detected distortions can indicate the presence and identity of nearby animals and other objects, especially objects with conductance different than water, (Lissman 1958, 1963 and Bullock, 1974). The system can be envisioned as a sort of "electrical sonar" for which there are certainly bionics applications. Note that in Table A.7 some eels and catfish are capable of producing high voltages utilized for stunning prey and discouraging predators, but this "shocking" capability is independent of electroreception capabilities.

Magnetic field sensitivity can be divided into three categories on the basis of the mechanism by which the magnetic field is detected. The first category is electromagnetic transduction. If a conductor is moved thru a magnetic field a current is induced in that conductor. Thus a shark (a conductor) moving through the earth's magnetic lines of force will induce an electric current in its body which can be detected by the passive electrosensitivity mentioned above, (Kalmijn, 1978). Thus electrosensitivity allows magnetic sensitivity, i.e., electromagnetic transduction. The second category involves direct magnetic sensitivity in which iron granules in the animals body respond to the magnetic field and somehow the animal detects that response and thus senses compass direction, (Kalmijn, 1977).

Bacteria, insects and snails utilize direct magnetic sensitivity for orientation. The third category of magnetosensitivity contains those systems for which there are no known mechanisms as in the magnetosensitivity of homing pigeons and possibly green sea turtles, (Fisher, 1979).

Elasmobranchs (especially sharks) are potentially useful animals for several reasons; their presence has strong psychological effects, some types of behavior can be readily controlled, they can be highly aggressive if so motivated and they posses exceptional chemoreception and electroreception. Because of this potential usefulness, shark electroorientation capabilities will be discussed in greater detail below. Other animals with electric and magnetic capabilities will be mentioned in a more general way in Section A.7.2.

A.7.1 Sharks, Skates and Rays (*Elasmobranchii*)

Sharks possess extremely sensitive passive electroreception with which they can detect slowly oscillating electric fields of as little as .01 μv./cm. D.C. fields and strong electrical stimuli cannot be detected. Typically prey animals produce bioelectric fields of threshold magnitude within 25 cm., and will produce osmotic electric fields detectable at over a meter, if their skin is damaged, (Kalmijn, 1971). By extrapolation a shark's electrosensitivity is the equivalent of detecting a flashlight battery at 1000 Km., but the system is noise limited in reality and functions within a range normally under one meter on local extremely weak fields. The sharks own electrical activity in muscle and nerve, worldwide lightning, solar storms, ionosphere fluctuations, current and temperature effects and chemical transductions are a few of the electrical sources that produce "noise" well above electrical threshold levels and thus limit the range of the system, (Kalmijn, 1974).

Electrosensitivity is utilized to detect visually and chemically hidden prey animals but it is also sensitive enough to respond to many other potentially useful environmental cues. Such stimuli within the threshold range include fluid bilayers at current boundaries, thermoclines or

salinity and chemical changes in water bodies, etc. Thus, by electrical transduction this information may be made available to the shark, (Schwassmann, 1978).

Sharks also possess a magnetic sensitivity facilitated by the electromagnetic transduction described above. This electromagnetic transduction can only occur if the shark is moving at a rate of at least 2.5 cm./sec., (Aekov and Ilyinski, 1976). Thus, if they are allowed to move, sharks and rays can be trained to choose among food boxes on the basis of the ambient magnetic field, (Kalmijn, 1978). In addition to sensing compass direction, it is probable that sharks can detect the latitude of their location by the verticle component of the earths magnetic lines of force. This capability would be useful in long distance migration. In summary, sharks can determine which direction they are moving and how fast and probably the latitude of their location. It is also likely that they can choose currents to aid in migration, can orient with respect to magnetic anomalies such as ore bodies in the sea floor, and can utilize a variety of other environmental information provided by electrical transductions.

A.7.2 Other Magnetic and Electrical Capabilities

Electrical and magnetic detection capabilities are surprisingly widespread as can be seen in Table A.7. Magnetic field sensitivity has been discovered in bacteria, (Kalmijn, 1977); insects, (Von Frisch, 1954 and Becker, 1963); snails, (Brown, 1963); and probably in the pigeon and green sea turtle, (Fisher, 1979). Sensitivity to electric fields has been discovered in protists, (Collias, 1980); flatworms, (Brown, 1963); and some fish, (Szabo, 1974). Active electroreception has been found in African and South American fresh water fish, (Murray, 1974). Details of active electroreception capabilities and mechanism can be found in Table A.7 under Gymnarchus and Gymnotus.

Table A.7. Parameters of Electroreception, Electroproduction, and Magnetic Field Sensitivity in Selected Animal Groups

GROUP	STIMULUS	THRESHOLD SENSITIVITY	BIOLOGICAL ROLES	RECEPTOR ORGANS
Marine and bacteria 13	earth magnetic field	< earth strength	orientation?	membrane mechanism?
Protist - paramecium	electric current	a few volts	sensitive to direction	
Flatworms 4	electric current			
Bees 7 22 & probably other insects also 2	magnetic field	< earth strength	navigation & orientation	iron granules present?
Snails 4 (land snails)	magnetic field	< earth strength	unknown	iron granules present
Sharks, skates, & rays, e.g., dogfish shark 3 6 9 10 11 14 17 18 19 20 1 12	fluid bilayer current	.01 μ V/cm field	orientation	Ampullae of Lorenzini
	Any low frequency (0-10 Hz) oscillating electric current, e.g., prey osmotic or bio electric fields	Not responsive to large stimuli .01 μ V/cm up to 25 cm (oscillating)	prey detection, localization & identification	" "
	Passive and active electrotransduction of magnetic fields	electrotransduction occurs at speed of 2.5 cm/sec.	migration, navigation orientation	" "
	also magnetic anomalies	variable	local orientation	" "
Fishes 5 15	active electrorientation	in mVolt range	detect objects	produces and receives small modulating voltage w/ specialized organs
Electric Eel 16 Electrophorus 21	& shocking capability	550 - 600 Volts	stun prey & predators	
South American Knife Fish, e.g. Gymnotus	self produced oscillating electric field & perturbations in that field. i.e., an electric analogue to echo-location	4.5 volt field between head & tail few Hz to 600 Hz- detects Δed conductance in field	detection of nearby objects	90 serial electrocytes produce potential. Ampullary organs receive signal.

Table A.7 continued

GROUP	STIMULUS	THRESHOLD SENSITIVITY	BIOLOGICAL ROLES	RECEPTOR ORGANS
African Knife fish Gymnarchus	active electro-orientation	3-6 ft. detects metal or glass rod 2mm diameter - a change of .03 μV/cm. is detectable. -material of object also discernable	detection of nearby objects	serial electrocytes produce currents - Ampullary receptors receive them
Tunas	electric fields	large & variable frequency	tunas swim into it	
Electric Catfish	-not stimulus - delivers an electric shock	350 volt shock deliverable	stun predators and prey	
Trout and salmon	electric field	detect & avoid large electric fields		
Reptiles e.g., Green Sea Turtle	magnetic field?	$<$ earth strength	migration?	
Birds 8 Pigeons	magnetic field	earth strength	homing	membrane mechanism or iron granules

A.8 MISCELLANEOUS CAPABILITIES AND CHARACTERISTICS

Some potentially useful capabilities and characteristics of animals cannot be classified under a specific sensory modality and thus will be mentioned in this section. The characteristics of animals to be described may be useful through supplementation of another capability or simply may provide a behavior or physiological characteristic that could prove useful in certain situations.

A.8.1 Miscellaneous Capabilities in Selected Animal Groups

The diving capabilities of animals may be useful to the Coast Guard. A variety of organisms can dive or withstand diving stresses. Examples are arthropods (e.g., lobster), the octopus, fish, sea turtles, birds, and marine mammals. Birds and marine mammals are of particular interest because they can be trained to perform complex tasks; however, these animals are also limited by the necessity of breathing air. The arthropods and the octopus are relatively depth insensitive but are more difficult to train. The diving capability of fish is limited by the presence of a swimbladder which regulates bouyancy but limits maximum depths and the rate of depth change. Sharks, tunas, and other fish without swimbladders are thus relatively insensitive to depth.

Marine mammals' diving capability is of particular interest. Many adaptations have occurred in marine mammals to overcome nitrogen narcosis, the bends, thermoregulation problems, pressure problems, and the need for oxygen (Alexander, 1975). Seals and sea lions are generally capable of relatively long dives to moderate depths. The deepest and longest pinniped dive measured thus far was accomplished by the Weddell seal (*Leptonychotes weddelli*). This large antarctic seal is capable of dives in icy water up to sixty minutes long with a maximum recorded depth of 600 meters. California sea lions are somewhat less spectacular, with dives on command to over 200 meters. The harbor seal will also dive to over 200-meter depths and is

capable of staying down up to 28 minutes. However, most pinnipeds are capable of dives about fifteen minutes long and normally descend to depths of only about 100 meters (Harrison, et.al., 1968).

Cetaceans are generally stronger swimmers and capable of deeper diving (Wood, 1973). Swimming strength is reflected in speeds obtained by some dolphins. The spotted dolphin has been clocked at 25 m.p.h. after a two-second acceleration. Tursiops has been clocked close to 20 m.p.h. Some examples of depth and endurance in diving by cetaceans are given below. Pacific bottlenose dolphins (Tursiops gilli) have been trained to dive, and in one test an individual made nine dives in sixty minutes to depths between 680 and 1000 feet with the longest dive being 4-3/4 minutes long. The maximum depth recorded for Tursiops gilli was 1700 feet (Linehan, 1979, NOSC deep dive program). The Pacific white sided dolphin will also dive to over 200 meters. Dalls porpoise (Phocoenoides) can dive faster and deeper, but they are fragile and difficult to maintain in captivity. Pilot whales are relatively easy to maintain in captivity and can dive to 1650 feet. Physter, a sperm whale, can dive for over an hour and reach depths of 1000 meters. Some whales can dive even longer; for example, Hyperoodon, the bottlenosed whale, can dive for over two hours.

Diving birds include the cormorants, grebes, diving ducks, pelicans, and ospereys (Welty, 1975). They are interesting because of the great mobility provided by flight combined with somewhat limited diving capabilities. Cormorants and grebes can see well under water and are fast and maneuverable enough to actively pursue and catch fish. The maximum diving ability in birds is achieved by the emperor penguin, a flightless species. This bird, on one dive, reached a depth of 265 meters and stayed down eighteen minutes.

Another noteworthy capability of animals is their ability to carry loads. Data is given here on a few potentially useful animals. Pigeons can

carry a twenty-gram package, and the larger turkey vulture can carry either 250 grams externally or 160 grams surgically implanted inside the body wall. The crow, an intelligent, easily trained intermediate sized bird, can carry a 100-gram package or 90 grams implanted in the body wall. Pigs can carry a 20-25 pound load in the abdomen with little discomfort. Dogs can also carry substantial loads, the actual amount, of course, depending on the breed. Load carrying capabilities in marine mammals are limited by drag rather than weight, since drag can significantly affect efficient swimming and thus limit the depth and endurance of the animal.

A.8.2 Miscellaneous Characteristics in Selected Animal Groups

Some potentially useful physiological and behavioral characteristics of animals are noted below.

Territoriality is a very common behavioral characteristic in many vertebrates and is often accompanied by highly aggressive behavior and conspicuous displays (Howell, 1979). If areas to be guarded could be made to correspond to territorial boundaries, the detection and guarding functions of animals could be greatly enhanced.

Hibernation is an adaptation for heat and energy conservation in bats, rodents, and a few small birds. Such a quality could be useful in systems with long periods of latency and occasional predictable use. An animal can lie dormant with little upkeep for long periods and then be aroused to perform a function.

Imprinting is a type of learning characterized by its permanence and irreversability once achieved, and the sensitivity to imprinting occurring only during an early sensitive period of the animal's life cycle. Many animals, notably birds, can be imprinted on home sites, parents, food, species recognition, etc. (Collias, 1980).

A potentially useful physiological mechanism is the use of hormones, pheromones, or drugs to induce a "primered" or ready state to perform certain behaviors. For example, hormonal injections can increase or decrease aggressiveness and territoriality or induce migrations in migratory species, etc.

Finally, high levels of genetic variability and rapid generation time make insects and bacteria good candidates for selective breeding. Genetic selection can be done on <u>any</u> heritable character including behavior, physiology, sensory ability, etc. (Manning, 1961; Benzer, 1973). This selection is most easily and rapidly achieved if a quantitative change in an already present characteristic is selected (Kikuchi, 1973; Wright, 1976; Manning, 1979).

A.9 REFERENCES

A.9.1 Vision References

1. Boden and Kampa Biolumenescence, In: Optical Aspects of Oceanography (Jerlov and Nielsen), Academic Press, London, New York, pp. 445-469, 1974.

2. Breland, M. Research on Avian Vision: Problems, Processes and Purported "Facts."

3. Clarke and Wertheim Measurements of Illumination at Great Depths and at Night by Use of a New Bathyphotometer, Deep Sea Res. 3, 1956.

4. Costeau, J. Y. Shark: Splendid Savage of the Sea. A & W Visual Library, New York, 1970.

5. The Visual Pigments of Geckos and Other Vertebrates: An Essay in Comparative Biology, In: Handbook of Sensory Physiology, Vol. VII, No. 5. (F. Crescitelli, ed.). Springer-Verlag, Berlin, Heidelberg, New York, pp. 391-451, 1977.

6. Denton, E. J. The Responses of the Pupil of *Gecko gecko* to An External Light Stimulus, J. Gen. Physiol. 40, 201-215, 1956.

7. Droscher, V. B. The Magic of the Senses. E. P. Dutton and Co., Inc. New York, 1969.

8. Gilbert, P. W. The Visual Apparatus of Sharks, In: Sharks and Survival. D. C. Heath, Boston, 1963.

9. Gruber, S. H. and J. C. Cohen Visual System of the Elasmobranchs: State of the Art 1960-1975, In: Sensory Biology of Sharks, Skates and Rays, (Hodgson, Ed. and R. W. Mathewson, Ed.), Office of Naval Research Alexandria, Va. 1978.

10. Gruber, S. H. and Myrberg, Jr., A. A. Approaches to the Study of the Behavior of Sharks Amer. Zool. 17:471, 1977.

11. Hamdorf, K. The Physiology of Invertebrate Visual Pigments, In: Handbook of Sensory Physiology, Vol. VII, No. 6A (H. Autrum ed.) Springer-Verlag, Berlin-Heidelberg-New York, 1979.

12. Harrison, Hubbard, Peterson, Rice, Schusterman The Behavior and Physiology of Pinnipeds. Appleton-Century-Crofts, New York, 1968.

13. Hess, Echkhard Sensory Processes In: Waters, Rolland, Rethlingshafer and Caldwell, Principles of Comparative Psychology. McGraw Hill, New York, 1960.

14. Horridge, G. A. Perception of Polarization Plane, Color and Movement in Two Dimensions By the Crab *Carcinus*. Z. Vergl. Physiol. 55, 207-224, 1967.

15. Hughes, A. The Topography of Vision in Mammals of Contrasting Life Style: Comparative Optics and Retinal Organization, In: Handbook of Sensory Physiology, Vol. VII, No. 5 pp. 613-757, 1977.

16. Kreithen, M.L. The Sensory World of the Homing Pigeon, In: Neural Mechanisms of Behavior in the Pigeon, (ed.) Granada, A.M. and Maxwell, S.H. Plenum Press, New York and London, 1979.

17. Lockett, N. A. Adaptations to the Deep Sea Environment, In: Handbook of Sensory Physiology, Vol. VII, No. 5, (F. Crescitelli, ed.) Springer-Verlag, Berlin, Heidelberg, New York, 1977.

18. Marks, W. B. Visual Pigments of Single Goldfish Cones, J. Physiol. (London) 178-14-32.

19. Marler, P. and W. Hamilton Mechanisms of Animal Behavior, John Wiley & Sons, Inc., New York, 1966.

20. Martinsen and Kimeldorf, 1972.

21. Menzel, B. Spectral Sensitivity and Color Vision in Invertebrates, In: Handbook of Sensory Physiology, Vol. VII, No. 6A (H. Autrum ed.) Springer-Verlag, Berlin-Heidelberg-New York, 1979.

22. Meyer, M. E. Discriminative Basis for Astronavigation in Birds, J. Comp. Physiol. Psycol. 58:403-406, 1964.

23. Meyer, D. B. The Avian Eye and Its Adaptations, In: Handbook of Sensory Physiology, Vol. VII, No. 5, (F. Crescitelli, ed.). Springer-Verlag, Berlin, Heidelberg, New York, pp. 549-614, 1977.

24. Milne, L. J. and M. Milne The Senses of Animals and Men. Athenum: New York, 1967.

25. Muntz, F. W. and W. N. McFarland Adaptations of Fishes to the Photic Environment, In: Handbook of Sensory Physiology, Vol. VII, No. 5 (F. Crescitelli, ed.) Springer-Verlag, Berlin-Heidelberg-New York, p. 193, 1977.

26. Nicol and Arnott Tapeta Lucida in The Eyes of Goatsuckers (*Caprimulgidae*), Proc. Roy. Soc. B. 187, 349-352, 1974.

27. Smythe, R. H. Vision in the Animal World, St. Martins Press, New York, 1975.

28. Walls, G. L. The Vertebrate Eye, Hafner Publishing Co., New York, 1963.

29. Wells, M. J. Octopus. Chapman & Hall, London, Halstead Press, John Wiley & Sons, New York, 1978.

30. Welty, J. C. The Life of Birds, W. B. Saunders Co., Philadelphia, London, Toronto, 1975.

31. Yager, D. and S. Thorpe Investigations of Goldfish Color Vision, In: Psychophysics, The Design and Conduct of Sensory Experiments. Appleton, Century, Crofts, New York, 1970.

A.9.2 Thermoreception References

1. Alexander, R.M. The Chordates. Cambridge University Press, Cambridge, London, New York, Melbourne, 1975.

2. Droscher, V.B. The Magic of the Senses. E.P. Dutton and Company, Inc. New York, 1969.

3. Firth, H. J. Incubator Birds, Sci. Amer. Vol. 201, No. 2, August 1959, pp. 52-58.

4. Hodgson, E. S. and R. W. Mathewson, eds. Sensory Biology of Sharks, Skates and Rays. Office of Naval Research, Alexandria, Va. 1978.

5. Milne, L. and M. Milne. The Senses of Animals and Men. Anthenum: New York, 1967.

6. Richards, O.W. and R. G. Davies. Imm's General Textbook of Entomology. Halsted Press, John Wiley and Sons, Inc., New York, 1977.

A.9.3 Chemoreception References

1. Amoore, J. E. Olfactory Genetics and Anosmia In: Handbook of Sensory Physiology, Vol. 4, Pt. 1. L. M. Biedler, Ed., Springer-Verlag, Berlin, Heidelberg, New York 1971.

2. Bang, B. G. and S. Cobb The Size of the Olfactory Bulb in 108 Species of Birds. Auk 85, 55-61, 1968.

3. Bedichek, R. The Sense of Smell. Doubleday and Co., Inc., Garden City, New York, 1960.

4. Berryman, R. Selection, Training and Control Problems in the Use of the Military Work Dog. Mississippi U. Biocontrol Systems, Bab., AFOSR TR74-0974, April 2, 1974.

5. Britt, K. The Joy of Pigs. National Geographic, Vol. 154, No. 3, Sept. 1978.

6. Collias, N. J. Lecture Series, UCLA, Jan. 1980.

7. Dethier, V. G. To Know a Fly. 1962. Holdenday, San Francisco, 1962.

8. Droscher, V. B. The Magic of the Senses. E. P. Dutton & Co., Inc., New York, 1969.

9. Engen, T. Olfactory Psychophysics. In: Handbook of Sensory Physiology, Vol. 4, Pt. 1, (p. 216-245). L. M. Biedler, Ed., Springer-Verlag, Berlin, Heidelberg, New York, 1971.

10. Gesteland, R. C. Neural Coding in Olfactory Receptor Cells. In: Handbook of Sensory Physiology, Vol. 4, Pt. 1, L. M. Biedler, Ed., Springer-Verlag, Berlin, Heidelberg, New York, 1971.

11. Gilbert, P. W., and R. F. Mathewson and D. P. Ralls, Eds., Sharks, Skates, and Rays. John Hopkins Press, Baltimore, 1967.

12. Grant, P. T. and A. M. Mackie Chemoreception in Marine Organisms. Academic Press, London - New York, 1974.

13. Grubb, Jr., T. C. Olfactory Guidance of Leach's Storm Petrel to the Breeding Island. Wilson Bull. (p. 91-141), 1979.

14. Gruber, S. H. and A. A. Myrberg, Jr. Approaches to the Study of the Behavior of Sharks. Amer. Zool. 17, (p. 471), 1977.

15. Hodgson, E. S. and R. W. Mathenson, (Eds.) Sensory Biology of Sharks, Skates and Rays. Office of Naval Research, Alexandria, Va. 22217, 1978.

16. Hutchinson, L. V. and B. M. Wenzel Olfactory Guidance in Foraging Procellariiforms. (Unpublished Manuscript Submitted for Publication), 1979.

17. Kaissling, K. E. Insect Olfaction In: Handbook of Sensory Physiology, Vol. 4, Pt. 1 (p. 351-432). L. M. Biedler, Ed., Springer-Verlag, Berlin, Heidelberg, New York, 1971.

REFERENCES (Continued)

18. Kent, R. Bausch and Lomb - Verbal communication, June 1974, by lead author.

19. Kikuchi, T. Genetic Alteration of Olfactory Function in *Drosophila Melanogaster*, Japan J. Genetics 48, (p. 105-118), 1973.

20. Lubow, R. E.. The Training and Use of Animals as Weapons of War In: The War Animals. Doubleday and Co., Inc., Garden City, New York, 1968.

21. Mathewson, R. R. and E. S. Hodgson Klinotaxis and Rheotaxis in Orientation of Sharks Toward Chemical Stimuli In: Comp. Biochem. Physiology 42A (p. 79-84), 1972.

22. McCartney, W. Olfaction and Odors. Springer-Verlag, Berlin, Heidelberg, and New York, 1968.

23. Milne, L. J. and M. Milne The Senses of Animals and Men. Atheneum, New York, 1967.

24. Moncrieff, R. W. The Chemical Senses, 3rd ed. Leonard Hill, London, 1967.

25. Moulton, D. G. Factors Influencing Odor Sensitivity in the Dog. U. of Pennsylvania, Philadelphia, Air Force Office of Scientific Research, Arlinfton, Virginia, AFOSR-TR-73-2337 AD A004 468, October 1974.

26. Ottoson, D. The Electroolfactogram In: Handbook of Sensory Physiology, Vol. 4, Pt. 1)p. 95-132). L. M. Biedler, Ed., Springer-Verlag, Berlin, Heidelberg, New York, 1971.

27. Papi, et.al. Pigeon Navigation: Effects Upon Homing Behavior by Reversing Wind Direction at the Loft, J. Comp. Phys. 128, (p.285., 1978a.

28. Papi, et. al. Do American and Italian Pigeons Rely on Olfaction for Homing?, J. Comp. Phys. 128, (pp. 303-317), 1978b.

29. Parsons, T. S. Anatomy of Nasal Structures From a Comparative Viewpoint In: Handbook of Sensory Physiology, Vol. 4, Pt. 1 (pp. 1-27). L. M. Biedler, Ed., Springer-Verlag, Berlin, Heidelberg, New York, 1971.

30. Pence, R. J. and P. Lomax The Excised Bee Abdomen in Medical Research, The American Bee Journal, Vol. 113, No. 12 (pp. 459-461), Dec. 1973.

31. Tester, A. L. Olfaction,Gustation and the Common Chemical Sense in Sharks In: Sharks and Survival (P. W. Gilbert), D. C. Heath and Co., 1963.

32. Southwest Research Institute Interim Technical Report on Olfactory Activity in Selected Animals During the Period June 1972-September 1974. Fort Belvior, VMDD, Sept. 1974 AD 787-495.

33. Waldvogel, et. al., Homing Pigeon Orientation Influenced by Deflected Winds at the Home Loft, J. Comp. Phys. 128,)pp. 297-302), 1978.

34. Wells, M. J. The Octopus. Chapman and Hall, New York, London, 1978.

35. Wenzel, B. M. Olfaction in Birds In: Handbook of Sensory Physiology, Vol. 4 Pt. 1,)pp. 432-448), L. M. Biedler, Ed., Springer-Verlag, Berlin, Heidelberg, New York, 1971.

36. Wenzel, B. M. Chemoreception in Sea Birds In: Burger, J. and B. C. Olla Behavior of Marine Animals; Current Perspectives in Research, Vol. 4, Marine Birds. Plenum Press, New York (In Press).

37. Wenzel, B. M. Chemoreception In: Farner, D. S. and J. R. King Avian Biology, Vol. 3, Chapter 6. Academic Press, New York, 1971-1975.

38. Von Frisch, K. The Dancing Bees: An Account of the Life and the Senses of the Honeybee. Trans. by Dora Ilse, Harcourt, Bruce and World. New York 1955. Methun and Co., Ltd. London (1954).

39. Wisby, W. J. and A. D. Hasler Effect of Olfactory Occlusion on Migrating Silver Salmon, J. Fish Res. Board Canada, 11 pp. 472-478, 1954.

40. Wright, R. H. Detecting Explosives - The Olfactory Approach. Proc. New Concepts and Symposium Workshop on Detection and Identification of Explosives. U.S. Depts. of Treasury, Energy, Justice, and Transportation. Oct. 30-Nov. 1, 1978.

41. Wright, R.H. Fruit Flies as Security Officers, Nature 260:92, London, 1976.

A.9.4 Audition References

1. Adams, W. B. (1971). "Intensity Characteristics of the Noctuid Acoustic Receptor" J. Gen. Physiol. 58, 562-579.

2. Alexander, R. M. (1975). The Chordates. Cambridge University Press, Cambridge London, New York, Melbourne.

3. Diercks, K. J., Trochta, R. T., Greenlaw, C. G. and Evans, W. E. (1971) Recording and Analysis of Dolphin Echolocation Signals, Journal Acoustic Soc. Am. 49, 6, pt. 1, 1729-1732.

4. Francis, R. L. Behavioral Audiometry in Mammals In: Sound Reception in Mammals, Eds. R. J. Bench, A. Pye, and J. D. Pye, Academic Press, London, 1975, pp. 237-289.

5. Gilbert, R. W. and Mathewson, R. F., Eds., (1967) Sharks, Skates and Rays. John Hopkins Press, Baltimore.

6. Haskell, P. T. (1956). "Hearing in Certain Orthoptera, I, II." J. Exp. Biol. 33, 756-766; 767-776.

7. Henson, O. W. (1975). "Comparative Anatomy of the Middle Ear." In: Handbook of Sensory Physiology, Vol. 5, No. 1. Springer-Verlag, Berlin, Heidelberg, New York.

8. Hodgson, E. S. and Mathewson, R. F., Eds., (1978). Sensory Biology of Sharks, Skates and Rays. Office of Naval Research, Alexandria, Virginia.

9. Johnson, C. S. (1968) Sound Detection Thresholds in Marine Mammals In: Marine Bioacoustics. Vol. 2, (w. N. Tavolga, ed.) 247-260 Pergammon Press.

10. Michelsen, A. (1975) "Hearing in Invertebrates." In: Handbook of Sensory Physiology. Vol. 5, No. 1. Springer-Verlag, Berlin, Heidelberg, New York.

11. Neff, W. D. et. al. (1975) "Behavioral Studies of Auditory Discrimination: Central Nervous System." In: Handbook of Sensory Physiology. Vol. 5, No. 2, Springer-Verlag, Berlin, Heidelberg, New York.

12. Nelson, D. R. and Burber, S. H. (1963) "Sharks: Attraction by Low Frequency Sounds." Sci., 142 (3594), 975-977.

13. Novick, A. (1958) Echolocation in Bats: Some Aspects of Pulse Design.

14. Payne, R. S., et. al. (1966). "Directional Sensitivity of the Ears of Noctuid Moths." J. Exp. Biol., 44, 17-31.

15. Richards, O. W. and Davies, R. G. (1977). Imm's General Textbook of Entomology. Halstead Press, John Wiley and Sons, New York.

16. Roeder, K. D. (1972) "Acoustic and Mechanical Sensitivity of the Distal Lobe of the Pilifer in Choerocampine Hawkmoths." J. Insect Physiol., 18, 1249-1264.

17. Roeder, K.D. and Treat, A.E. (1957). "Ultrasonic Reception by Tympanic Organs of Noctuid Moths." J. Exp. Zool. 134, 127-157.

18. Sales, G.D. "Auditory Evoked Responses in Small Mammals"In: Sound Reception In Mammals. Ed., R. J. Bench, A. Pye, and J. D. Pye, Academic Press, London, 1975, pp. 189-190.

19. Schwartzkopff, J. (1955)."On The Hearing of Birds." AUK, 72:340-347.

20. Smith, J. B. (1968)."Hearing in Terrestrial Urodels: A Vibration Sensitive Mechanism in the Ear." J. Exp. Biol. 48, 191-206.

21. Welty, J. C. (1975). The Life of Birds. W. B. Saunders Co., Philadelphia, London, Toronto.

22. Wever, E. G. (1975). "The Evolution of Vertebrate Hearing." In" Handbook of Sensory Physiology. Vol. 5, No. 1., Springer-Verlag, Berlin, Heidleberg, New York.

23. Wisby, W. J., Richard, J. D., Nelson, D. R., Bruber, S. H. (1964). "Sound Perception in Elasmobranchs." In: Marine Bioacoustics. (Tavolga, W. N., Ed.) Pergamon Press, New York.

24. Wright, B. (1948). "Releasers of Attack Behavior Patterns in Shark and Barracuda." J. Wildlife Management. 12(2) 117-123.

A.9.5 Echolocation References

1. Alexander, R.M. (1975) The Chordates. Cambridge University Press. Cambridge, London, New York, Melbourne.

2. Andersen, S. (1970b.) "Directional hearing in the harbor porpoise (Phocoena phocoena)", in Investigations on Cetacea Vol. II. G. Pilleri (ed.). Benteli Ag. pp. 260-263.

3. Arms, K. and P. Camp (1979) Biology. Holt, Rinehart and Winston. New York, Chicago, San Francisco, Atlanta, Dallas, Montreal, Toronto, London, Sidney.

4. Au, W.W.L., R.W. Floyd, R.H. Penner and A.E. Murchison (1974) "Measurement of echolocation signals in the Atlantic bottle nose dolphin, Tursiops truncatus, in open waters. J. Acoust Soc. Am. 56(4):1280-1290.

5. Ayrapet'yants, E. Sh. and A. I. Konstantinov (1973) Echolocation in Animals. Israel program for scientific translations, Ltd.

6. Ayrapet'yants, E. Sh. and A. I. Konstantinov (1974) Echolocation in Nature, Parts I and II. Nauka, Leningrad. 506 pages. (English translation JPRS 63328).

7. Bagdonas, A., V. M. Bel'kovich and N. L. Krushinskaya (1970) Interaction of analyzers in dolphins during discrimination of geometrical figures under water, Jour. Higher Neural Act., 20:1070 (English translation in: "A Collection of Translations of Foreign Language Papers on the Subject of Biological Sonar Systems," K. J. Diercks, 1974, ed., Applied Research Lab, U. of Texas, Austin, Tech, Rept. 74-9).

8. Barta, R. E. (1969) "Acoustical pattern discrimination by an Atlantic bottle-nosed dolphin," unpublished manuscript, Naval Undersea Center (Naval Undersea Cneter (Naval Ocean Systems Center), San Diego.

9. Bastian, J.R. (1967) "The transmission of arbitrary environmental information between bottlenose dolphins." In: Animal Sonar Systems: Biology and Bionics (R.G. Busnel, ed.) Vol. II. pp.803-873. Laboratorie de Physiologie Acoustique. Jouy-en-Josas-78, France.

10. Bel'kovich, V.M., I.V. Borisov, V.S. Gurevich and N.L. Krushinskaya (1969) Echolocating capabilities of the common dolphin (Delphinus delphis), Zoologicheskiy Zhurnal, 48:876 (English translation JPRS 48780).

11. Bel'kovich, V.M. and N.A. Dubrovskiy (1976) "Sensory Bases of Cetacean Orientation," Nauka, Leningrad (English translation JPRS L/7157).

12. Bloedel, P. Hunting methods of fish eating bats, particularly Noctilio leporinus. Jour. of Mammology, Vol. 36, Ho. 3, August 1955, pp. 390-399.

13. Bullock, T.H. A. D. Grinnel, E. Ikezono, K. Kameda, Y. Katsuki, M. Nomoto O. Sato, N. Suga and K. Yanagisawa (1968) "Electrophysiological studies of central auditory mechanisms in cetaceans," Z. Vergl. Physiol. 59:117-156.

14. Busnel, R.G. and A. Dziedzic (1967) "Resultats metrologigues experimentaux de l'echolocation chez le Phocaena phocaena et leur comparison avec ceux de certaines chauves - souris" in Animal Sonar Systems, Biology and Bionics, Vol. I. R.-G. Busnel (ed.). Laboratoire de Physiologie Acoustique, Jouy-en-Josas, France. pp 307-335.

15. Busnel, R.G., A. Dziedzic, and S. Anderson (1965) Seuils de perception du systéme sonar du Marsouin Phocoena phocoena, en fonction du diamétre d'un obstacle filiforme, C. R. Acad. Sci., 260:295.

16. Cummings, W.C. and P.O. Thompson (1971) "Underwater sounds from the blue whale, Balaenoptera musculus. Jour. Acoustical Soc. Am., 50 (4 pt. 2) 1193-1198.

17. Diercks, K.J., R.T. Trochta, C.F. Greenlaw, and W.E. Evans (1971) "Recording and analysis of dolphin echolocation signals." Jour Acoustic Soc. Am. 49, (6, pt. 1):1729-1732.

18. Evans, W.E. (1967) "Vocalization among marine mammals." In: Marine Bio-acoustics Vol. II. (W.N. Tavolga, ed.) pp. 159-186. Pergammon Press.

19. Evans, W.E. and J. Bastian (1969) "Marine mammal communication; social and ecological factors." In: The Biology of Marine Mammals (H.T. Andersen, ed.) pp. 425-475. Academic Press.

20. Evans, W.E. and B.A. Powell (1967) "Discrimination of different metalic plates by an echolocating delphinid." In: Animal Sonar Systems - Biology and Bionics. Vol.1 (R.G. Busnel, ed.) pp. 363-383. Laboratorie de Physiologie Acoustique, Jouy-en-Josas-78, France.

21. Evans, W.E. and R. Haugen (1963) "An experimental study of the echolocation ability of the California sea lion Zalophus californianus." Bull. Southern Calif. Acad. Sci. 62(4):165-175.

22. Evans, W.E. (1973) "Echolocation by marine delphinids and one species of freshwater dolphin," J. Acoust. Soc. Amer. 54:191-199.

23. Evans, W.E. and P.F.A. Maderson (1973) "Mechanisms of sound production in delphinid cetaceans: A review and some anatomical considerations," Amer. Zool. 13:1205-1213.

24. Fish, J.F. and H.E. Winn (1969) "Sounds of marine animals." Encyclopedia of Marine Resources. (F.E. Firth, ed.). Van Nostrand Reinhold Co.

25. Gould, E. (1965) "Evidence for echolocation in the Tenrecidal of Madegascar." Proc. Amer. Philosoph. Soc. Vol. 109, No. 6:352-360.

26. Gould, E.N., C. Negus and A. Novick (1964) "Evidence of echolocation in shrews." J. Exp. Zool., Vol. 156, No. 1. 19-38.

27. Griffin, D.R. (1958) Listening in the Dark. Yale University Press, New Haven, 413 pp.

28. Hall, J.D. and C.S. Johnson (1972) "Auditory thresholds of a killer whale Orcinus orca." Jour. Acoustical Soc. Am. 51, (2, Pt. 2):515-517.

29. Hammer, C.E. (1978) "Echo-recognition in the porpoise (Tursiops truncatus): an experimental analysis of salient target characteristics," San Diego. NOSC Tech. Rep. 192. Naval Ocean Systems Center. 18 pages.

30. Jacobs, D.W. and J.D. Hall (1972) "Auditory thresholds of a freshwater dolphin Inia geoffrensis. Jour. Acoustical Soc. Am. 51(2, Pt. 2): 530-533.

31. Johnson, C.S. (1967a) "Sound detection thresholds in marine mammals." In: Marine Bioacoustics, Vol. 2, (W.N. Tavolga, ed.) 247-260. Pergammon Press.

32. Kellogg, W.N. (1958) "Echo ranging in the porpoise," Science. 128:982-988.

33. Lilly, J.L. (1967) The Mind of the Dolphin. Doubleday and Company.

34. Mohres, F.P. (1966) "General characters of acoustic orientation signals and performance of sonar in the order chiroptera." In: Animal Sonar Systems, Biology and Bionics. Vol. 1, Laboratorie de Physiologie Acoustique. Jouy-en-Josas, France.

35. Moore, P. Cetacean Obstacle Avoidance, In: Animal Sonar Systems, R. G. Busnel and J. F. Fish, Eds., Plenum Publ. Corp., N.Y., 1980.

36. Murchison, A. Earl and Paul E. Nachtigall (1977) "Three dimensional shape discrimination by an echolocating bottlenose porpoise (Tursiops truncatus)," Proceedings (Abstracts) of the Second Conference on the Biology of Marine Mammals, San Diego. p. 37.

37. Murchison, A.E. (1980) "Maximum Detection Range and Range Resolution in Echolocating Tursiops truncatus (Montague), Ph. D., dissertation U. of Calif. at Santa Cruz, Calif. (manuscript).

38. Murchison, A.E. (1979) Detection Range and Range Resolution of Echolocating Bottlenose Porpoise (Tursiops truncatus), In: Animal Sonar Systems R. G. Busnel and J. F. Fish, Eds., Plenum Publ. Corp., N.Y., 1980.

39. Nachtigall, Paul E. in press. "Odontocete echolocation performance on object size, shape and material," In: Animal Sonar Systems, R. G. Busnel and J. F. Fish, Eds., Plenum Publ. Corp., N.Y., 1980.

40. Nachtigall, Paul E., A. Earl Murchison and W.W.L. Au (1978) "Discrimination of solid cylinders and cubes by a blindfolded echolocating bottlenose dolphin (Tursiops truncatus," J. Acoust. Soc. Am. 64(1):587.

41. Norris, K.S. W.E. Evans and R.N. Turner (1967) "Echolocation in the Atlantic bottlenose porpoise during discrimination." In: Animal Sonar Systems: Biology and Bionics. (R. G. Busnel, (ed.) Vol. 1, pp. 409-437. Laboratorie de Physiologie Acoustique. Jouy-en-Josas-78, France.

42. Norris, K. S. J. H. Prescott, P.V. Asa-Dorian and P. Perkins (1961) "An experimental demonstration of echolocation behavior in the porpoise, Tursiops truncatus (Montagu)," Biol. Bull. 120(2):163-176.

43. Norris, K.S., G.W. Harvey, L.A. Burzell and T.D. Krishna Kartha (1972) "Sound production in the freshwater porpoises Sotalia cf. fluviatilis Gervais and DeVille and Inia geoffrensis Blainville, in the Rio Negro, Brazil," In: Investigations on Cetacea, Vol. IV. G. Pilleri (ed.) Benetelli, Ag. Berne. pp. 251-259.

44. Novick, A. (1958) "Echolocation in bats: Some aspects of pulse design."

45. Novick, A. (1959) "Acoustic orientation in the cave swiftlet." Biol. Bull. Vol. 117, No. 3. 497-503.

46. Poulter, T.C. (1966) "Systems of echolocation." In: Animal Sonar Systems, Biology and Bionics, Vol. 1. Laboratorie de Physiologie Acoustique. Jouy-en-Josas, France.

47. Riley, D.A. and Rosenzweig, M. (1957). "Echolocation in rats." J. Comp. Physiol. Psyc. Vol. 50:323-238.

48. Rosenzweig, M.R., D.A. Riley and K. Krech (1955) "Evidence for echolocation in the rat." Science. Vol. 121:600.

49. Schusterman, R.J. (in press) "Behavioral methodology in echolocation by marine mammals," In: Animal Sonar Systems, R. G. Busnel and J. F. Fish, Eds., Plenum Publ. Corp., N.Y. 1980.

50. Schusterman, R.J. and D. Kersting (1978) "Selective attention in discriminative echolocation by the porpoise (Tursiops truncatus)," Paper read at the Animal Behavior Society Annual Meeting, June 19-23, U. of Wash., Seattle.

51. Tavolga (1977) "Mechanisms for directional hearing in the sea catfish (Arius felis). J. Exp. Biol. 67:97-115.

52. Thompson, R.O and W.C. Cummings (1969) :Sound production of the finback whale, Balaeoptera physalus and Eden's whale, B. Edeni, in the Gulf of California. (abstract). Proceedings of the 6th annual conference of biological sonar and diving mammals, Stanford Research Inst.

53. Titov, A.A. (1972) Reviewed in Ayrapet'yants and Konstantinov, 1974.

54. Turner, R.N. and K.S. Norris Discriminative echolocation in a porpoise, Jour. of the Exp. Anal. of Beh., 9:535.

55. Wood, F.G. (1973) Marine Mammals and Man. The Navy's Porpoises and Sea Lions. Robert B. Luce, Inc., Washington-New York.

56. Wood, F.G., D.K. Caldwell and M.C. Caldwell (1970) "Behavioral interactions between porpoises and sharks." In: Investigations on Cetacea. Vol. II. (G. Pilleri, ed.).

57. Wood, F.G. and W.E. Evans "Adaptiveness and Ecology of Echolocation in Toothed Whales. In: Animal Sonar Systems, R. G. Busnel and J. F. Fish, Eds., Plenum, 1980.

A.9.6 Tactile Sensitivity References

1. Burgess, P.R. and Pearl, E.R. "Cutaneous mechanoreceptors and nociceptors." In: Handbook of Sensory Physiology, Vol. 2. Springer-Verlag, Berlin, Heidelberg, New York. 1973.

2. Hartline, P.H. J. Exp. Biol. 54., 349-372. 1971.

3. Richards, O.W. and Davies, R.G. Imm's General Textbook of Entomology. Halsted Press, John Wiley and Sons, Inc., New York. 1977.

4. Smith, I.D. "The trigeminal system." In: Handbook of Sensory Physiology, Vol. 2. Springer-Verlag, Berlin, Heidelberg, New York. 1973.

5. Smith, J.B. "Hearing in terrestrial urodels: A vibration sensitive mechanism in the ear." J. Exp. Biol. 48, 191-206. 1968.

6. Wells, M. J. Octopus: Physiology and Behavior of an Advanced Invertebrate Chapman and Hall, London, 1978.

A.9.7 Electroreception and Electroorientation References

1. Akoev, G.N., Ilyinsky, O.B., Zadan, P.M. Responses of electroreceptors (Ampullae of Lorenzini) of skates to electric and magnetic fields. J. Comp. Physiol. 106, 127-136 (1976).

2. Becker, G. Rest positions according to direction of skies: a magnetic field orientation in termites. Naturwissenschaften 50 (12) p. 455 (1963).

3. Bennett, M.V.L. Physiology of the ampullae of Lorenzini, the electroreceptors of elasmobranchs. In: Sensory Biology of Sharks, Skates, and Rays. Office Naval Research. Department of Navy. Arlington VA. (1978).

4. Brown, F.A., Jr., How animals respond to magnetism. Discovery 24 (11) p. 18-22 (1963).

5. Bullock, T.H. Seeing the world thru a new sense: Electroreception in fish. Am. Scientist. 73, 316-325 Rev.

6. Bullock, T.H. An essay on the discovery of sensory receptors and the assignment of their functions together with an introduction to electroreceptors. In: Handbook of Sensory Physiology, Vol. 3 #3."Electroreceptors and other specialized receptors in lower vertebrates."A. Fessard (ed.), Springer, Berlin (1974).

7. Collias, N.J. Lecture series at UCLA 1/80-3/80.

8. Fisher, A.L. Mysteries of bird migration. Nat. Geographic Vol. 156 #2, Aug. 1979.

9. Hodgson, E.S. and Mathewson, R.W. (eds.) Sensory Biology of Sharks and Rays. Office of Naval Research, Alexandria VA 22217.

10. Kalmijn, A.J. Electro-perception in sharks and rays. Nature (Lond.) 212, 1232-1233 (1966).

11. Kalmijn, A.J. The electric sense of sharks and rays. J. Exp. Biol. 55, 371-383 (1971).

12. Kalmijn, A.J. The detection of electric fields from inanimate and animate sources other than electric organs. In: Handbook of Sensory Physiology, Vol. 3 #3. "Electroreceptors and other specialized receptors in lower vertebrates." A Fessard (ed.), Springer, Berlin (1974).

13. Kalmijn, A.J. Animal orientation, detection of electric and magnetic cues proceeding of the international union of physiological sciences. Vol. XII Lecture 0.30, p. 60 (1977).

14. Kalmijn, A. J. Electric and Magnetic Sensory World of Sharks, Skates, and Rays. In: Sensory Biology of Sharks, Skates and Rays. E. S. Hodgson and R. W. Mathewson, Eds. Office of Naval Research, Alexandria VA (1978).

15. Lissman, H.W. On the function and evolution of electric organs in fish. J. Exp. Biol. 35, p. 156-159, (1958).

16. Lissman, H.W. Electric location by fishes. Sci. Amer.(March) 208, No. 3, P. 50-59, (1963).

17. Murray, R.W. The ampullae of Lorenzini. In: Handbook of Sensory Physiology. Vol. 3 #3."Electroreceptors and other specialized receptors in lower vertebrates." A. Fessard (ed.), Springer, Berlin,(1974).

18. Schwassmann, H.O. Ecological aspects of electroreception. Bk. 04869 Nato advanced study institutes series. Vol. 18,521-533 37 Rev. (1978).

19. Szabo, T., Kalmijn, A.J., Enger, P.S., Bullock, T.H. Microampullary organ in the fresh water ray, Potamotrygon, J. Comp. Physiol. 79, 15-27 (1972).

20. Szabo, T. Anatomy of the specialized lateral line organs of electro-reception. In: Handbook of Sensory Physiology. Vol.3 #3,"Electroreceptors and other specialized receptors in lower vertebrates." A. Fessard (ed.), Springer, Berlin (1974).

21. Szabo, T., Fessard, A. Physiology of electroreceptors. In: Handbook of Sensory Physiology. Vol 3 #3, "Electroreceptors and other specialized receptors in lower vertebrates. A. Fessard (ed.), Springer, Berlin,(1974).

22. Von Frisch, Karl. The Dancing Bees: An Account of the Life and Senses of the Honeybee. Trans. by Dora Ilse. Harcourt, Bruce and World. New York (1955). Methun and Co., Ltd., London (1954).

A.9.8 Miscellaneous Capabilities and Characteristics References

1. Alexander, R.M. The Chordates, Cambridge University Press, Cambridge - London - New York - Melbourne, 1975.

2. Benzer, S. "Genetic dissection of behavior." Scientific American, 229 (6) 24-37, (1973).

3. Blackwelder, R.E. Classification of the Animal Kingdom, Southern Illinois University Press, Carbondale, Illinois.

4. Collias, N.J. Lecture series at UCLA, 1980.

5. Harrison, Hubbard, Peterson, Rice, Schusterman. The Behavior and Physiology of Pinnipeds, Appleton-Century-Crotts, New York, 1968, p. 214.

6. Howell, T.R. Lecture series at UCLA, 1979.

7. Kikuchi, T. "Genetic alteration of olfactory function in Drosophila melognaster," Japan J. Genetics 48, p. 105-118, 1973.

8. Linehan, E.J.,"The trouble with dolphins." National Geographic, Vol. 155, No. 4, April 1979.

9. Manning, A. "The effects of artificial selection for mating speed in Drosophilia melognaster," Animal Behavior, 9, 82-92.

10. Manning, A. An Introduction to Animal Behavior. Addison-Wesley Publishing Company, London, 1979, p. 208.

11. McGraw, Hill, Encyclopedia of Science and Technology. McGraw-Hill Book Company, New York, San Francisco, St. Louis, 1971.

12. Welty, J.C. The Life of Birds. W.B. Saunders and Co., Philadelphia, London, Toronto, 1975.

13. Wood, F.G. Marine Mammals and Man, The Navy's Porpoises and Sea Lions, Robert B. Luce, Inc., Washington - New York, 1973.

14. Wright, R.H. "Fruit flies and security officers," Nature, 260:92, London, 1976.

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